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Examining the Dynamics of Infant Face Processing Using State Space Grids

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EXAMINING THE DYNAMICS OF INFANT FACE PROCESSING USING STATE SPACE GRIDS

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Abstract

In this investigation we examined the potential processes underlying infant preferences for and categorization of male and female faces as well as the outcome of these preferences. Infants with female primary caregivers exhibit preferences for same-race females over males and categorize females more readily than males. Little is known, however, about how infants may arrive at these collective preferences and categorization abilities. In research settings infants are exposed to novel stimuli in relatively short periods of time, and their experiences outside of the lab may be imposing structure onto their learning in lab settings. We used state space grids (SSGs) to examine how the dynamic systems concepts of attractor states, stability, and variability related to infant behavior in two experimental contexts. The content and variability of infant behavior differed based on infant age, study context, and real-world social experiences. Additionally, within-person differences in the variability of looking patterns were associated with the strength of attractor states, which suggests that real-time dynamics impacted behavioral outcomes.

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Chapter 1: Examining the Dynamics of Infant Face Processing Using State Space Grids

Infants are inundated with novel and familiar situations every day, and how they adapt and learn from these fleeting and recurring experiences is an exceedingly intriguing aspect of development. Every outing to the grocery store or park is a tumultuous landscape intermixed with new sensory experiences, budding social interactions, and an underlying familiarity that grows with each excursion. From staring down the muzzle of a fuzzy, four-legged, panting beast that licks and slobbers to gawking up at a less-fuzzy, two-legged, smiling granny who tickles and chatters, infants learn about people and animals. Every food, textured surface, and Gymboree class is an opportunity for infants to make new connections, solidify existing associations, and gain additional experiences in their ever-changing environments.

One such novel situation is that encountered during the typical infant looking time research paradigm. Infants are shuttled into a windowless room in the middle of an academic oasis, situated on sensory-deprived parents' laps or secured in car seats to nowhere, and plopped in front of TV monitors, projection screens, or minimalist-inspired, make-shift puppet theatres. They are then presented with any number of stimulus displays and scenarios including gender-ambiguous faces (e.g., Younger & Fearing, 1999), monkey faces (e.g., Pascalis, de Haan, & Nelson, 2002), dog faces on cat bodies and cat faces on dog bodies (e.g., Spencer, Quinn, Johnson, & Karmiloff-Smith, 1997), projectiles with occluded trajectories (e.g., Rosander & von Hofsten, 2004), or puppets engaged in complex situations with hidden objects and unknowing confederates (e.g., Onishi & Baillargeon, 2005). All of these events happen in a matter of minutes as Oz-esque researchers loom behind partitions or curtains and monitor infants demonstrating complex cognitive processes like categorization, discrimination, memory retention, and intermodal sensory matching. Within these very brief testing scenarios, however, researchers discover that infants can group, discriminate, recognize, match, and detect physical anomalies.

As researchers, we may lose sight of the novelty of these situations and often our analytic endeavors indicate as such. Developmental researchers might overlook the learning that may be occurring within a research study. We often rely on statistical analyses that collapse data across trials and participants and compare aggregate values across experimental manipulations. It is likely, however, that infants are gaining experience and adapting to their environments even in these short testing sessions. Comparing group means is important and has taught us much about infant development, but researchers could supplement their existing analytic repertoire with measures and analyses that help uncover the processes underlying infant behavior. We have learned a great deal about where infants look, and now we should direct some efforts to understanding how and why infants look (Aslin, 2007). By focusing on the variability within and between participants and examining changes in behavior across time (i.e., real-time research settings as well as developmental time), researchers may better understand the processes underlying infant behavior during looking time paradigms and the role that real-world experience may play.

In this investigation we examined the potential processes underlying infant behavior in two experimental designs with multiple contexts. We examined infants’ preferences for male and female faces of different races/ethnicities and attractiveness levels within two contexts, one in which stimulus presentation was more predictable than the other. We also examined infants’ categorization of male and female faces that differed in attractiveness and femininity. We were interested in not only understanding the collective outcome of infant behavior during these contexts, but also sought to acquire a better understanding of the processes that may be underlying infant performance during these tasks – particularly in instances when infants did not exhibit group preferences or categorization for faces. In both investigations we used a dynamic systems perspective to help frame our hypotheses and focus our analyses on uncovering potential differences among the processes underlying infant behavior.

Dynamic Systems

A dynamic systems perspective arises from multiple disciplines including biology, physics, and psychology (e.g., Thelen & Smith, 2006). From a developmental psychology perspective, a dynamic systems approach focuses on the interactions among changing processes as they unfold over time (e.g., Hollenstein, 2013; Kelso, 1995; Thelen & Smith, 2006). The developing organism (i.e., system) is made up of interacting elements across multiple levels or domains including molecular, physical, emotional, social, or cultural, and change can arise across multiple timescales from milliseconds to years (e.g., Thelen & Smith, 2006). Although psychology tends to focus on systems at the level of the organism, a system can be any biological or physical process (e.g., Thelen & Smith, 2006). Proponents of dynamic systems tout it as a metatheory that provides a framework for uncovering change and understanding emergent behavior across a variety of domains and phenomena (e.g., Granic & Hollenstein, 2003; Hollenstein, 2013; Lewis, 2005; Thelen & Smith, 2006). Therefore, dynamic systems is not necessarily in opposition to existing domain-specific theories, but instead seeks to provide a means of explaining the process underlying a particular phenomenon (e.g., Hollenstein, 2013). Proponents of dynamic systems seek to unify our understanding of development under one conceptual framework that focuses on the variability and complexity of change processes across domains (e.g., Fogel, 2011; Hollenstein, 2011; Lewis, 2011; Spencer, Perone, & Buss, 2011; van Geert, 2011; Witherington & Margett, 2011).

As a domain-general perspective for discovering change, developmental researchers have used dynamic systems to understand development in an array of contexts. Esther Thelen and colleagues explored infants' motor development with a focus on how contextual factors influence the emergence and disappearance of motor behaviors such as reaching and stepping (e.g., Spencer et al., 2011; Thelen, Fisher & Ridley-Johnson, 1984; Thelen & Ulrich, 1991). For example, Thelen et al. (1984) discovered that newborns' stepping behavior was related to differences in leg strength. They examined the emergence and disappearance of the stepping reflex by systematically manipulating variables related to leg strength (e.g., an infant who did not show stepping behavior under normal conditions did so when their body weight was supported by being submerged in waist-deep water). Their focus on variability within and between participants helped uncover the specific contexts in which coordinated actions across multiple components of the infant system facilitated changes in motor skills (e.g., Spencer et al., 2011; Thelen & Ulrich, 1991).

Researchers have expanded upon Thelen's work in motor development to include exploration of aspects of embodied cognition, working memory, and visuospatial learning (Hollenstein, 2011; Spencer et al., 2011). One important contribution is the line of research deconstructing infant behavior during the A-not-B task, which is a Piagetian task assessing object permanence (i.e., the understanding that objects exist even if they cannot be directly observed; Piaget & Cook, 1954). The task entails the retrieval of hidden objects from one of two locations and often involves participants making a retrieval error (i.e., perseveration) in which they reach for the hidden object in the previously learned A location instead of the current B location. In the typical execution of this task, infants around 8 to 10 months will make this error; by 12 months, however, infants will accurately search in the new, B location (e.g., Smith & Thelen, 2003). Through a number of experiments, simulated data sets, and behavior modeled with dynamic field theory models (i.e., a modeling technique that depicts changes in behavior as activation among interconnected layers that represent system components), researchers demonstrated that the A-not-B error could occur in relation to many different contexts including the prior history of reaching behavior (e.g., Smith, Thelen, Titzer, & McLin, 1999). When the context of reaching between A and B events was altered (i.e., an infant sitting during A events and standing during B events), 8- to 10-month-olds performed like 12-month-olds (Smith et al., 1999). On the other hand, toddlers and children as old as 6 years could succumb to the A-not-B error if researchers manipulated the distance between A and B locations or made A and B locations more ambiguous by burying items in sand (e.g., Schutte, Spencer & Schöner, 2003; Spencer, Smith, & Thelen, 2001). These task manipulations helped researchers develop a more comprehensive understanding of perseverative reaching during development (i.e., Spencer et al., 2011).

Researchers such as Alan Fogel, Paul van Geert, and Marc Lewis have applied a dynamic systems lens to explain such developmental processes as emotional regulation, personality formation, and social interactions (Hollenstein, 2011). For example, Fogel and Thelen (1987) explained infants’ changing communication processes (i.e., crying and smiling) through the coordinated action of multiple components (i.e., physical aspects of respiratory strength and motor control, affective and cognitive development, and motivational and social factors). For example, they posited that infants transition from a few cries to many, elaborate cries in part because of cognitive and affective maturation. The coordination of low-level physical components such as lung capacity and oral muscle development allow for more complex cries to emerge.

Lewis and colleagues have contributed to our understanding of infants and children's social interactions by exploring the dynamics of dyadic and group relationships during coordinated activities and conflict resolution (e.g., Hollenstein & Lewis, 2006; Lewis et al., 1999; Lewis, Zimmerman, Hollenstein, & Lamey, 2004; Martin et al., 2005). Much of Lewis's work has also focused on the dynamic interaction between real-time and developmental-time (Hollenstein, 2011). Lewis (2005) proposed a model to explain the interactions among momentary real-time emotional states, more persistent moods, and long term personality development. For example, experiencing an emotional state of anger, may impact a person's mood for the next few minutes or even hour and during this time anger states are more likely to recur (as compared to happy states). Thus the real-time emotional state impacts more persistent moods, and moods constrain the next potential real-time emotional state. If these recurrent events persist for longer periods of time, they could impact aspects of personality, which again, will likely constrain the moods and emotional states for that person in a circularly causal manner (Hollenstein, 2013; Lewis, 2005).

At its core, dynamic systems posits that systems at every level (from the coordinated hand movements necessary to pick up a pencil to the price of cotton on the global market) are self-organizing and multicausal, and that this organization arises from fluctuations and changes within the system (e.g., DiDonato, England, Martin, & Amazeen, 2013; Granic & Hollenstein, 2003; Hollenstein, 2007; Kelso, 1995; Lewis, 2000; Smith & Thelen, 2003; Thelen & Smith, 2006). Dynamic systems offers a conceptual framework to help researchers examine the "process" of developmental change (Granic & Hollenstein, 2003; Hollenstein, 2007; Lewis, 2000).

This framework is, in part, built upon theories from the natural sciences, such as dynamical systems in mathematics and chaos theory in physics, and employs many of the same concepts and terms as these theories. Within a developmental perspective of dynamic systems, the focus of interest (a single child, a parent-child dyad, a classroom) is described as the system. A system may possess the potential for an infinite number of behavioral patterns, yet most often only a few potential behaviors are likely to occur for a particular system. These behaviors are described as states, and the interconnection among states occurs within the state space, which is a multidimensional space that comprises all possible states of the system (e.g., Hollenstein, 2013). The current states of a state space can be depicted as a three-dimensional plane (i.e., attractor landscape) of undulating peaks and valleys, and the behavior of the system can be tracked across the surface of the plane (or hyper-plane) by a ball or point that meanders among the peaks and valleys (e.g., Hollenstein, 2013; Martin, Fabes, Hanish, & Hollenstein, 2005). The movement of the system on the plane is measured by changes in the dependent variable (sometimes referred to as the collective variable or order parameter; e.g., Kelso, 1995; Thelen & Ulrich, 1991) and can be influenced by the peaks and valleys, which represent states of attraction or repulsion for the system (i.e., attractors and repellors, respectively). Attractors (the valleys) are portions of the state space in which the system visits frequently and represent stable behaviors for the system. The strength of an attractor is represented by the depth and breadth of the attractor region in the state space. (See Figure 1 for a three-dimensional, pictorial representation of a set of attractors and repellors that have converged for a hypothetical state space; from Martin et al., 2005.)

To illustrate these concepts using an example of emotional states, imagine that Figure 1 represents the current emotional landscape of a participant who is experiencing a negative mood. Even though the participant has the capacity to feel any number of emotions at any given time, the overarching negative mood has constrained the emotional landscape so that only a few potential emotional states are likely to occur. Each emotional state is an attractor on the landscape, and the participant's current feelings of emotion would be represented by a point or ball on the landscape. In this example, attractor A may be an emotional state of anger. Because of its depth and steepness, A may represent a stable state; one for which it would be difficult for the participant to escape. Attractors B and C might represent slightly less intense negative emotions such as contempt or sadness. Both attractors are shallow, and attractor B is quite broad, which indicate states that are less stable. It would be easier for the participant to move in and out of these states, and he may visit them with some frequency. State D would likely represent a positive emotion such as happiness; given the current context of a negative mood, it might be nearly impossible for the participant to maintain a feeling of happiness for even a short period of time.

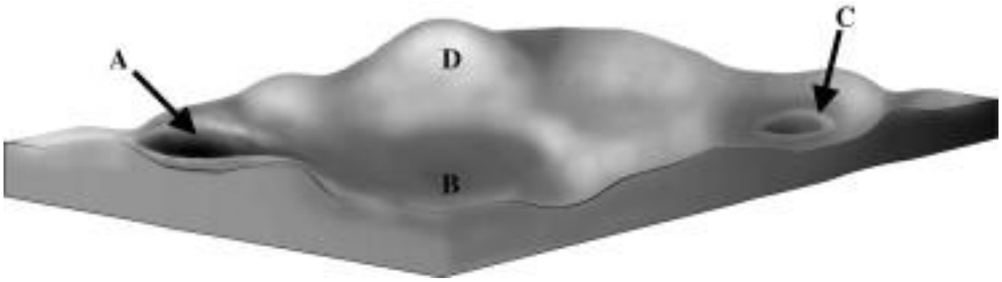

*Figure 1.*A hypothetical set of attractors (A, B, and C) and repellor (D). The strength of attractors is represented by the depth and breadth of the wells and indicate states in which it is difficult for a system to escape (A) or likely for it to visit frequently (B). The steepness of repellors indicates behaviors that are unlikely to occur or from which a system will quickly escape (from Martin et al., 2005).

Dynamic systems are open systems, which mean they interact with external forces. Environmental factors can influence a developing system and act as agents for change (e.g., Hollenstein, 2013). As a system's behavior becomes more stable, the depth and/or breadth of stable attractors increase while attractor states visited infrequently by the system may eventually flatten out. During periods of change in the system's behavior (e.g., transitions from earlier developmental stages to more advanced behaviors), the state space is described as being quite unstable, and outside influences (i.e., perturbations) can be more impactful in structuring the eventual stable state space. These changes to the state space of a system are called phase transitions, are often nonlinear, and represent qualitative shifts in the system's attractor landscape (e.g., Hollenstein, 2013; Kelso, 1995; Thelen & Ulrich, 1991).

Again, using the negative mood example, imagine that the participant experiences an environmental perturbation such as attending a birthday party. It is unlikely that his mood will instantly switch from negative to positive, but as he experiences positive events from the party atmosphere, his negative states may destabilize, and his emotional landscape may reconfigure to one in which the states of anger and happiness have less extreme valleys and peaks. Even though he may still experience anger, he may be able to escape it more readily, and he may be able to stay in states of positive affect for longer periods of time. If the outside influence persists, it could eventually change his emotional attractor landscape entirely, and his negative mood and emotional states may be replaced by positive mood states.

Change from a dynamic systems perspective is described through the concept of self-organization. One key component to self-organization is the interaction among lower-order states to arrive at higher-order states of the system (e.g., Hollenstein, 2013; Kelso, 1995). Thus, higher, more complex behaviors arise from the interconnection and coordination of lower-level, simpler components without outside instruction (e.g., Spencer et al., 2011; Thelen & Smith, 2006). For example, when an infant is learning to reach for an object, at first the arm may flail randomly as muscles in the arm spontaneously flex and relax, but if the infants' hand inadvertently touches an object, that sensory information feeds back into the system. With repeated flexing and relaxing of lower-level muscles and continued haptic feedback from the object, the behavior becomes more stable and reaching eventually arises at a higher-level coordinated action of extending, positioning, and grasping. These interactions among the systems' components can be spontaneous, are based on the current context of the system, and are not predetermined or built into the system (e.g., Smith & Thelen, 2003; Spencer et al., 2011; Thelen & Ulrich, 1991). Although new, more complex behaviors arise through this emergent process, dynamic systems are not one-directional. All components of the system interact in a multicausal manner on many levels (e.g., Hollenstein 2013; Smith & Thelen, 2003). Higher-order states can influence the likelihood of lower-order states to recur (e.g., personality or mood influencing current emotional states), and emergence or stability of a state does not necessarily indicate that state has become the dominant behavior pattern for the system. Dynamic systems are softly assembled, meaning that components of the system interact and assemble into a stable pattern based on the current context of the system (e.g., to solve a current problem), but then may destabilize and reconfigure into an alternate stable state given a different context (e.g., Spencer et al., 2011; Thelen & Ulrich, 1991).

A dynamic systems perspective also describes change within the context of nested timescales (e.g., Fogel, 2011; Smith & Thelen, 2003). Time is often depicted in two general (although somewhat ambiguous) contexts: that which occurs globally at the macrolevel and that which occurs locally at the microlevel (e.g., Fogel, 2011). Macrolevel change is developmental change on a broad scale. Macrolevel change may emerge slowly (months or even years) and represents more stable behaviors that arise from phase transitions when the attractor states and landscape of the system are likely to change (e.g., Lewis et al., 1999). Microlevel change is typically focused on moment-to-moment changes in the real-time observation of the system. Microlevel changes can be small shifts in a system’s structure brought on by outside perturbations that result in the system spontaneously assembling on a new attractor (Lewis et al., 1999). For example, a child who is experiencing a developmental change to her locomotor landscape, such as learning to walk, will likely go through a period of transition in which both walking and crawling are stable states that are equally likely to occur in the same microlevel context. As walking becomes a more stable state and the dominant macrolevel structure, however, the child may engage in crawling only when outside perturbations such as an uneven terrain lead her to momentarily assemble into a crawling pattern. Self-organization can occur across multiple timescales and has a recursive quality in that small-scale patterns of change can repeat in a fractal pattern (i.e., a pattern that is repeating and self-similar across multiple scales). Microlevel changes, therefore, can be the foundation for developmental change on a much larger scale (e.g., Fogel 2011; Thelen & Smith, 2006). Because change is a continuous, fluid process, phase transitions can also be captured in real-time analysis (Spencer & Perone, 2008).

Another component of dynamic systems that contributes to developmental science is the evaluation of variability within and between individuals (e.g., Hollenstein, 2013; Smith & Thelen, 2003; Thelen & Ulrich, 1991). Given a multicausal environment in which momentary patterns of behavior can emerge and disappear based on the context at hand and previous history of the system, variability among system components and across individuals is likely to be paramount. A dynamic systems perspective calls for researchers to embrace variability and use it to explore how behavior patterns emerge and stabilize in particular contexts (e.g., Hollenstein, 2013; Smith & Thelen, 2003; Thelen & Smith, 2006; Thelen & Ulrich, 1991). For example, children use a variety of strategies to solve math problems (e.g., Siegler & Crowley, 1991). Even though they eventually use advanced strategies with more frequency, children still often rely on earlier, slower strategies to solve problems and will use a variety of strategies within the same problem-solving session.

The notion of placing variability at the forefront of an investigation of change is likely to result in patterns of change that are somewhat chaotic and nonlinear in their progression. Dynamic systems researchers, therefore, have generated a variety of design considerations and analytic tools to help capture variability and emergent change processes within and between developing organisms (e.g., DiDonato et al., 2013; Fogel, 2011; Spencer et al., 2011). These techniques have allowed researchers to uncover processes underlying many aspects of infants' socioemotional, motor, and cognitive development, but there are still more avenues to explore. For example, a dynamic systems perspective could help researchers uncover the interplay between infant development at the macrolevel (i.e., real-world experiences outside of the lab) and microlevel changes and learning that occur during lab settings.

From laboratory experiments, we make many inferences about infants' cognitive and social abilities outside of the lab, yet we might be able to enhance our understanding of the learning that occurs during testing by exploring infant behavior through dynamic systems approaches. We know that infants look at certain stimuli more than others, but we are far less certain as to why they may be looking. Infants can learn associations quickly during a relatively brief training session (i.e., a few minutes or even a single trial), remember word-object associations, or recall a familiar stimulus and show preferences for a novel one. Therefore, attending more to the rapid learning that occurs during testing sessions could be quite insightful into uncovering the underlying processes behind infants' looking behavior.

Aslin (2007) suggested that much ambiguity lies in our understanding of the link between infant looking and the underlying processes looking may represent. Because much of infant research relies on a global measure of infant looking (i.e., dependent variables of looking time aggregated across testing sessions and participants), the hypotheses researchers test and the conclusions they draw may be limited. Aslin (2007) advocated for researchers to improve upon infant research techniques and ask more subtle research questions. He encouraged further exploration of the looking time measure through comparison with converging measures like heart rate and ERP. Integrating concurrent measures of physiological responding with behavioral assessments of infant looking will aid researchers in discovering how lower-level components coordinate to create higher-order states in response to the research context at hand (e.g., Aslin, 2007; Bremner, 2011; Smith & Thelen, 2003; Spencer et al., 2011; Thelen & Ulrich, 1991).

Aslin (2007) also suggested that researchers incorporate a more microscopic measure of looking through eye-tracking techniques or more nuanced variables like frequency of looks, look duration, or look away information. Dynamic systems may offer a framework on which to build a conceptual understanding of looking behavior that occurs during research paradigms. By applying the concepts of variability and attractor stability to our interpretation of research outcomes, we can better address the learning that may be occurring during our lab settings (i.e., infants may adapt quickly to new experiences and novel stimuli in the lab setting and converge on patterns of behavior or preferences that did not exist prior to the lab experience). By embracing the variability that exists within our research participants, we can create a more intricate picture of the many ways in which development arises (i.e., by not assuming that infants' performance on a single task represents a stable ability; e.g., Smith & Thelen, 2003). By exploring change across the lab study, we can examine how learning on small time scales (i.e., seconds) may relate to learning across larger time scales (i.e., cumulative experience; e.g., Smith & Thelen, 2003).

Infant Face Processing: Macrolevel and Microlevel Patterns of Change

Of particular interest to this investigation is uncovering the multicausal relations between infants' real-world experiences with faces and their real-time dynamics during lab settings with facial stimuli. In particular we sought to investigate the constraints that macrolevel social experience may impose upon infants' behavior during preference and categorization studies involving male and female faces. Having a better understanding of the reciprocal nature of the relation between macrolevel and microlevel change may help us interpret infant behavior during testing situations.

Infants who have female primary caregivers experience more interactions with females than males. Nearly 70% of their social interactions are with females including more interactions with familiar females (i.e., family and friends) and female strangers than with familiar males or male strangers (Rennels & Davis, 2008; Sugden, Mohamed-Ali, & Moulson, 2014). Infants also tend to have more interactions with people from the same race or ethnicity as their primary caregiver (i.e., 88% of social interactions are with familiar race faces; Rennels & Davis, 2008, Sugden et al., 2014). These data suggest that familiar race females typically dominate infants' social context.

This early experience with females influences infants' face processing in lab settings. Although newborns do not show preferences for females over males, within a few short months, 3-month-olds exhibit preferences for familiar race females relative to familiar race males (e.g., Quinn, Yahr, Kuhn, Slater, & Pascalis, 2002; Quinn et al., 2008). By 3 months, infants also show better abilities to recognize female than male face exemplars (e.g., Quinn et al., 2002). Infants, however, can adapt quickly to environmental changes. For example, Sangrigoli and de Schonen (2004) demonstrated that 3-month-olds could recognize an other-race face if they saw multiple exemplars during familiarization but did not show evidence of recognition when they saw just one exemplar during habituation. These results suggest that even though infants' macrolevel social context may often impose a familiar face structure (i.e., familiar race) onto infants' performance during research settings, it may not do so in all contexts. The microlevel learning that occurs during lab settings (i.e., experience with multiple exemplars) might temporarily reorganize infants' face processing structure and lead to infants performing differently during some research contexts.

To investigate how environmental factors from real-world social experiences interact with microlevel learning during lab settings, we examined infant behavior in several different contexts across two research paradigms. We used the dynamic systems concepts of variability and attractor stability to guide our examination of infant looking time data. First we examined infants' spontaneous preferences for females and males in two contexts: one with a more predictable structure than the other. To measure spontaneous preferences, we used a visual paired comparison (VPC) paradigm that involved showing infants competing stimuli in side-by-side comparisons over consecutive trials (e.g., Fantz, 1956; 1958b). Researchers make inferences about infants' spontaneous preferences for one stimulus over another based on where and how long infants look.

Second, we examined infant's categorization abilities for females and males in four different contexts in which we manipulated the content of the to-be-learned category.

Categorization studies allow researchers to test infants' cognitive abilities to discriminate and group items with similar properties (e.g., Mareschal & Quinn, 2001). Researchers often assess infants' categorization abilities by first familiarizing or habituating infants to a single category of stimuli and then testing them with paired comparisons of novel exemplars (one from the just-learned category and one from a category that differs in some dimension of interest). Researchers must also assess for a priori preferences for the test stimuli because infants may exhibit preferences for one stimulus over the other due to characteristics of the stimuli (e.g., real-world experience or salience) and not due to learning during the familiarization phase (Quinn, 1987).

To capture dynamic patterns of change, we focused on applying state space grids (SSGs) to our infant looking time data. SSGs are two-dimensional grids that are used to graphically represent all potential states of the system under investigation. The system's behavior is plotted as a trajectory of events within the grid that unfold across time. Researchers use SSGs to analyze a variety of measures related to the content and structure of the system (e.g., Hollenstein, 2011). Many analytic tools exist for exploring dynamic systems concepts (e.g., DiDonato et al., 2013; Spencer et al., 2011), and applying a SSG analysis to such a simple system as a VPC paradigm might not be entirely necessary. Other techniques such as time-series analyses could also capture change in this context (e.g., Bakeman & Gottman, 1997; Heath, 2000). SSGs, however, allow for the discovery of "pooled" areas of behavior that are not as dependent on a sequential progression of events as traditional time-series analyses (Lewis et al., 1999). We chose to use the SSG technique as an entry point to dynamic systems analytical techniques for two reasons: (a) Hollenstein (2013) provides a detailed handbook for using the GridWare package, calculating variables, and offers suggested analyses and (b) we could potentially expand the SSG technique into other, more complex infant paradigms (e.g., comparing infant looking time data contingent with other physiological measures or with more detailed measures of looking behavior such as eye-tracking data; Aslin, 2007).

SSGs offer a way of mapping real time dynamic change (Hollenstein, 2007; 2013; Lewis et al., 1999). Researchers can use SSGs as a descriptive tool for visualizing data, as a means to generate variables related to content and structure, or as a more theoretical and conceptual source for creating hypotheses related to the “process” that underlies behavior (Hollenstein, 2013). Through the use of the GridWare software package (Version 1.1; Lamey, Hollenstein, Lewis, & Granic, 2004), researchers can plot ordinal or categorical data in a two-dimensional context to examine how a system’s behavior changes in real-time. The represented state space often comprises two dimensions on which the system varies simultaneously (i.e., infant looking behavior and affective responding during a frustrating toy scenario; Lewis et al., 2004). Each dimension is divided into mutually exclusive and exhaustive categorical or ordinal components on the SSG (Hollenstein, 2013). The progression of the system through time can then be plotted as a trajectory that passes through the different cells of the state space (cells represent potential points of intersection between the two dimensions plotted along the x- and y-coordinates).

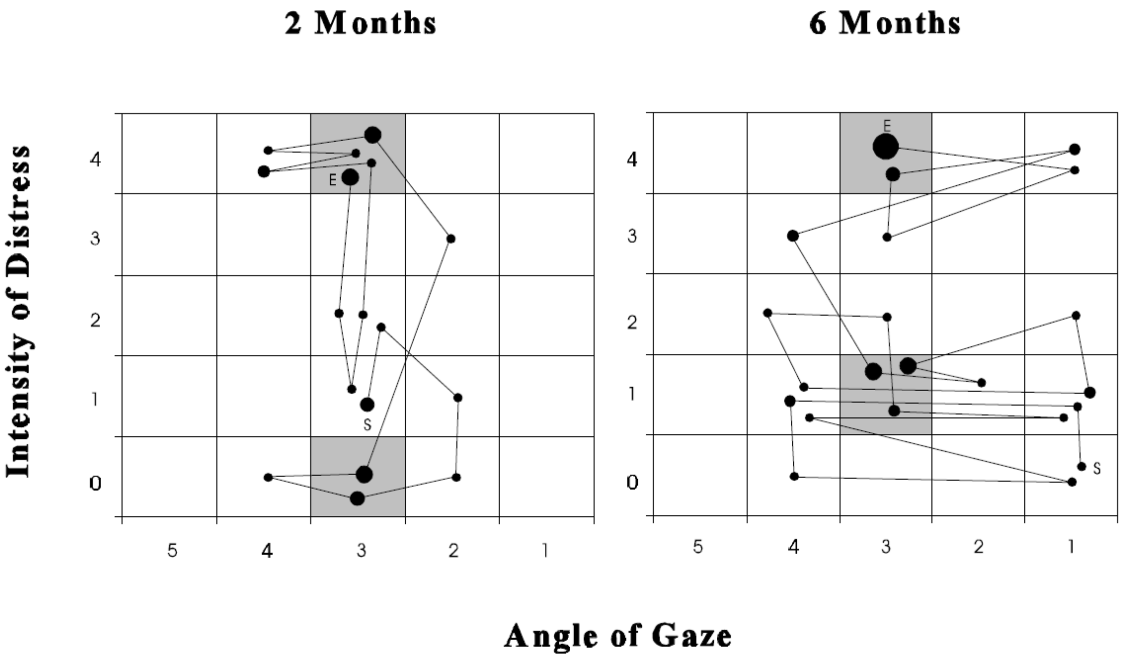

*Figure 2.*Two state space grids (SSGs) for the same infant at 2 months and 6 months. This figure demonstrates cross-age stability for the top attractor (i.e., toward the end of the observational period at both ages, the infant became intensly distressed but maintained a neutral gaze in which she was “gazing plus or minus 30 degrees from midline or playing with her own hands or clothes”) but showed a general decrease in the “attractiveness” of either attractor at 6 months due, in part, to longer return times to the attractor states (from Lewis et al., 1999).

To illustrate, Figure 2 shows two SSGs for an infant at 2-months and 6-months. Researchers coded infants’ behavior in 1 s increments for 30 s (at 2 months) and 45 s (at 6 months) after the mother returned from a separation sequence. The x-axis depicts all possible states of the infant’s angle of gaze with respect to mother and is represented as an ordinal variable (1 = on-face to 5 = cut-off [60-90 degrees beyond midline]). The y-axis depicts all possible states of the infant’s distress level and is also represented as an ordinal variable (0 = contentment to 4 = intense distress). Each cell on the grid represents a potential intersection between the infant’s angle of gaze and level of distress. The trajectory of the infant’s behavior can be tracked by starting at the ‘S’ and ending at the ‘E’. The diameter of each node indicates the length of time in each state, and the highlighted cells indicate regions of attraction for that infant (as empirically determined through a winnowing procedure devised by Lewis et al., 1999). To track the pattern of behavior for the 2-month testing session when the parent returns, the infant starts in a somewhat content state with a neutral gaze (cell 3,1). She becomes slightly less content and her focus is closer to looking at the mother (cells 3,2 and 2,1) until she settles on a content state with a neutral gaze (cell 3,0). Then the infant jumps to a state of distress but maintains a neutral gaze (cell 3,4), exhibits a brief period of content, but ends the 30 s session in a distressed/neutral gaze state. Patterns are somewhat similar for the 6-month testing session. Although the infant starts in a content state that is focused on the parent (cell 0,1) and switches focus from the parent to off the parent more often, the infant exhibts a somewhat content and neutral gaze state early in the session and ends in a distressed/neutral gaze state by the end of the 45 s session.

SSG analysis allowed Lewis and colleagues (1999) to uncover the process underlying emotional changes by providing a way to identify participants’ frequency and stability of emotional states (i.e., attractors) that was independent of the content of the emotional states. For example, Figure 2 demonstrates not only that this infant showed cross-age stability for the top attractor (i.e., similar content across the two testing sessions) but also a general decrease in the “attractiveness” of all attractor states at 6 months (i.e., longer return times to attractor states regardless of the specific state).

From SSGs, researchers can gather variables that measure the strength of attractors within a system and the stability of the system on various time scales (DiDonato et al., 2013; Hollenstein, 2007; 2013; Martin et al., 2005). Measures can relate to both the content of the system (e.g., duration and frequency of certain attractors) and structure of the system (e.g., configuration of attractors; Hollenstein, 2013). See Table 1 for a select list of the types of measures that can be acquired from GridWare software. Here we highlight measures that appear to be most pertinent for capturing the variability and content of infant behavior during looking paradigms, but see Hollenstein (2013) for a complete list of measures.

Table 1

Description of State Space Grid Measures Available from the GridWare Software Package

Measure *	Description	Meaning of high values
Cell range	Number of cells visited by the trajectory	High variability, low stability
Dispersion	Sum of squared proportional duration across all cells corrected for # of cells. Dispersion is: $1 - \frac{(n\sum(d_i/D)^2) - 1}{n - 1}$ Where: D is total duration d_i is duration in cell i n is total number of cells	High variability, behavior dispersed across SSG
Number of visits	Total number of nodes for a trajectory	High variability
Transitions	Number of times system switches states (# of visits – 1)	High variability
Visit entropy	Predictability of trajectory's sequence of states. Visit entropy is: $\sum(P_i * \ln(1/P_i))$ Where: i is an index of each cell on the grid P_i is number of visits to cell i divided by total number of visits for the entire trajectory	Highly unpredictable
First entry	Mean, across trajectories, of time until first entry into cell or region	Weak attraction
Return time	Average duration of intervals between visits to a cell or region	Weak attraction
Mean duration per visit	For a cell or region, total duration in a cell or region divided by # of visits to cell or region	Strong attraction

* Each measure can be applied to a variety of time scales and contexts including the entire system, specified windows of time, or specific cells (adapted from Hollenstein, 2013; Martin et al., 2005).

Hollenstein (2013) describes variability in two forms: that which reflects moment-to-moment contextual changes in the system and that which reflects a system's adaptation to environmental influences and perturbations. Moment-to-moment changes in variability are often observed through measuring interactions within one level and are captured via within-grid analyses (e.g., comparing variability in infants' looking behavior toward familiar and unfamiliar race faces). Variability related to environmental influences is better captured through examining changes across time and is measured using between-grid analyses (e.g., the changes in variability of infant behavior across an entire study or after a perturbation such as a familiarization sequence). In both instances variability can be understood as the overall pattern of data within a grid (i.e., whole grid analysis) regardless of the structural components of the grid (i.e., attractor states). The measures of cell range, dispersion, transitions, and visit entropy are often examined to capture variability (see Table 1; Hollenstein, 2013). Although cell range can provide a conceptual understanding of the system's repertoire (i.e., total number of cells visited by a given trajectory), dispersion may be a more meaningful measure when the duration of each event is represented on the state space (Hollenstein, 2013).

To capture the content of a system, researchers focus on identifying attractor states and measuring their strength and stability. Attractors can be identified by applying the aforementioned, whole-grid variables to specific cells or regions on the grid or by calculating region-specific variables that are obtained using information about transitions between cells or time in specific cells. The region-specific variables most likely to contribute to our understanding of infant behavior during looking time paradigms include first entry, return time, and mean duration per visit (see Table 1). Each of these variables could help capture the relative strength of attractor states within a grid with only a few possible states, such as a looking time paradigm. The converse to first entry is last exit, which is the last time the trajectory transitioned out of a specific cell. Both low first entry and high last exit times are indicative of strong attractors because they may mean that a trajectory entered that attractor region early and visited it late. A cell with a shorter return time constitutes a stronger attractor than a cell with a longer return time because a shorter return indicates a cell for which it is difficult for a trajectory to escape (Hollenstein, 2013). Often attractors are determined through a combination of variables; a strong attractor is one in which a system visits frequently, stays for a long period of time, and returns to frequently and quickly (Hollenstein, 2013). For infant looking behavior during a VPC task, only three potential attractor states are possible (i.e., stimulus A, stimulus B, and away). Researchers can, therefore, use these variables to identify which of these states is most stable or strongest for each infant for a particular trial or phase of a study. For example, a face to which an infant returns quickly or frequently or to which the infant looks for a long time without looking away may indicate that face is an attractor for that infant.

Once attractors have been identified, the strength and stability of attractors across time can be explored. Hollenstein (2013) suggests either examining the relative strength of attractors across time (e.g., correlation of attractor strength between two time points; Lewis et al., 1999), or creating a new SSG to track stable attractors across each time point. This attractor “on the state space” approach would entail identifying the most stable attractor at each time point, then creating a new grid for each participant to track the pattern of the attractor states across time points. Either technique could be effective for exploring the stability of attractors across VPC trials. Because there are so few potential attractor states, researchers could examine the relative strength of the three potential states across trials using growth analyses. Researchers could also identify the most stable attractor for each infant for each trial and then map the trajectory of stable attractors across trials.

Social and developmental researchers have used SSGs and a variety of variables to examine dynamic flexibility and change. Many researchers have used SSGs to investigate interpersonal interactions within dyads or groups (e.g., parent-child emotional states during conflict resolution; Granic & Lamey, 2002; Granic, O'Hara, Pepler, & Lewis, 2007; Hollenstein & Lewis, 2006, or peer selection among preschoolers; Martin et al., 2005). Hollenstein & Lewis (2006) investigated the emotional patterns of mother-daughter dyads engaged in a conversation that consisted of a sequence of positive, conflict, and positive events, respectively. They used the measures of transitions, dispersion, and duration in negative emotional states during each segment of conversation and conducted repeated-measures ANOVAs with planned quadratic contrasts for each variable. They determined that during conflict discussion the dyads experienced more negative emotions, fewer transitions, and lower levels of dispersion than during the two positive discussions. Low values for transitions and dispersion indicated that the dyads were less flexible during periods of conflict.

SSGs have also been used as a descriptive tool for uncovering patterns of behavior. Meindertsma, van Dijik, Steenbeek, and van Geert (2014) were interested in the complexity and content of kindergartners' explanations for floating and sinking objects, and how children's explanations might change during a single testing session. They used SSGs to explore individual patterns of change, level of complexity, and content for 14 objects that floated or sank. Visual inspection of children's behavioral trajectories revealed that most children who had higher levels of variability in performance stabilized by the end of the task. These children used only one level of complexity and content in their explanations, which indicated learning during the course of the task and stabilizing to one preferred attractor state.

In infant research, SSGs have shown patterns of infant-mother engagement and affect during face to face interactions (Provenzi, Borgatti, Menozzi, & Montinrosso, 2015), how toddlers' coping strategies change when dealing with frustrating toys (Lewis et al., 2004), and how infants' socioemotional development changes from 2 to 6 months (Lewis et al., 1999). Lewis and colleagues (1999) discovered that even though infants' behavioral states varied greatly across participants, in general, infants tended to have more stable and cohesive emotional states at 6 months than 2 months, regardless of the specific emotional states. They also noted that this content-free, organizational perspective extended upon more conventional assessments of emotional development. In this instance, Lewis et al. measured stability of attractors using return time, and then examined attractor stability by correlating return time across the two testing sessions. See Figure 2 for sample SSGs of an infant at two time points; from Lewis et al., 1999.

Examining infant looking time data from the lens of SSG analyses could contribute to our overall understanding of the processes behind infant behavior during preference and categorization studies. Understanding the strength and stability of attractors could be quite meaningful to understanding infant preferences and learning. For example, an infant may spend an equal amount of time looking at two stimuli, but one stimulus may be more of a stable attractor than the other (i.e., the infant engages in longer looks toward that stimulus). Examining infants' overall patterns of behavior (regardless of the content of the behavior) could help us understand the process underlying infants' preferences. For example, focusing on changes in variability during a testing session could help us understand if and how infants may be learning about stimuli and adapting to the novel testing environment. If infants exhibit different patterns of behavior toward different types of stimuli, these patterns could help us better understand how the context may be related to the outcome of the behavior (e.g., if infants have more stable, less variable looking patterns when looking at familiar faces). Having a better understanding of the patterns in which infants look during a research setting can help researchers make richer interpretations of infant behavior and potentially provide more nuanced insights into instances when infants appear to have no significant preferences for stimuli.

Present Study

In this investigation we examined how infants' cumulative experiences with faces outside of the lab impacted their preferences for and categorization of male and female faces in lab settings. We also investigated how infants' behavior was influenced by the real-time dynamics of the lab setting. Infants may learn and adapt quickly during these novel research settings and, therefore, may perform differently from the beginning to end of a testing session or under different experimental designs or manipulations.

Using SSGs to guide this investigation, we (a) compared dynamic aspects of variability in infant looking behavior across ages and/or experimental contexts, (b) assessed changes in variability across the time course of the testing sessions, and (c) determined the strength and stability of attractor states. Because we expected that macrolevel social structure and microlevel learning would interact in ways that might influence both between- and within-person effects, we chose analytical approaches that did not assume independence and allowed for correlations among observations (i.e., SAS proc mixed and hierarchical linear modeling; Garson, 2012; SAS Institute Inc., 2011).

By comparing variability across ages and contexts, we determined whether infants exhibited different patterns of looking under certain experimental constraints. For example, we predicted that infants would have less variable or more predictable looking patterns (i.e., low dispersion and visit entropy) during settings in which they saw familiar stimuli (i.e., familiar race faces, female faces, and/or high attractive faces) as opposed to trials with less familiar stimuli. Stimuli that are familiar should also be stronger and more stable attractor states, and strong, stable attractors are characterized by stable patterns of behavior (i.e., Hollenstein, 2013). By assessing the changing patterns of variability across time, we determined the role of real-time dynamics. For example, we anticipated that infants would exhibit more variable looking (i.e., higher dispersion and visit entropy) at the beginning as opposed to the end of a testing session because they must first adapt to the novelty of the testing session and then settle into stable looking patterns as their environment becomes more familiar. Additionally, if infants exhibited a brief period of instability in the middle of a study, then those infants may have experienced a momentary perturbation or even potential phase transition brought on by the lab setting that altered their performance. For example, we anticipated that infants would experience a momentary increase in variability during the first trial of a block of trials or the first trial of a new phase of a study.

To determine what these potential structural patterns might mean, we also examined the content of infants' behavior (e.g., Hollenstein, 2013). To capture the content of infant looking, we identified potential attractor states and assessed their relative stability and strength across the time course of the testing session. By understanding how and when attractor states changed and stabilized, we better understood the qualitative aspects of infant behavior during our study designs and determined how macrolevel and microlevel changes might be influencing behavior. For example, we predicted that infants would experience the strongest, most stable attractor states for stimuli most similar to their real-world experiences. For example, infants would show the strongest and most stable attractor states (i.e., highest proportion of looking) for familiar race female faces in the preference study or for high attractive, high feminine female faces during the categorization study.

For each experiment we compared results obtained during traditional looking time analyses to results obtained during SSG analyses in order to determine if a dynamic systems perspective contributed additional information to our understanding of infant looking in each design setting. We used data from two studies currently being conducted in our lab. Data collection is almost complete for both studies. I have been highly involved in both projects from their early stages. For Experiment 1, I am involved in daily management of data collection and helped set up protocol for data management. For Experiment 2, I was involved in designing the study, preparing stimuli, and managing data. I oversee the daily operations for this study, conduct reliability, and manage many aspects of this project.

Chapter 2: Experiment 1

Infants' preferences for faces appear to be related to their real-world experiences. Infants with female primary caregivers show a preference for females when paired with males (e.g., Quinn et al., 2002), but these preferences appear to be specific to females from familiar races (e.g., Quinn et al., 2008). It is unclear whether infants' preference for females extends to face pairs of different levels of attractiveness because Quinn et al. (2002, 2008) used high attractive face stimuli (models from magazines and facial averages). This investigation examined the malleability of infants' preference for females by showing infants male and female face pairs from four different races and three attractiveness levels. We also investigated how contextual factors related to the predictability of the study design might influence infants' preferences by showing infants face pairs that were either (a) randomized across race and attractiveness levels or (b) blocked by race. Early preferences are an initial step in discovering how attention to others impacts categorical knowledge and learning of social groups (e.g., Ramsey, Langlois, Hoss, Rubenstein, & Griffin, 2004), so understanding these contextual effects is important.

This study design allowed us to understand how macrolevel and microlevel structures of infants' social worlds might interact. We analyzed data from infants who had Caucasian, female primary caregivers only in order to constrain infants' potential macrolevel social experiences (i.e., infants typically have much more experience with same-race, female faces than other face types; Rennels & Davis, 2008; Sugden et al., 2014). We also compared infants aged 3- to 4-months and 9- to 10-months to understand how macrolevel factors such as cumulative social experience during the first year and developmental maturation (e.g., age-related differences in face processing and regulating attention toward stimuli) might be related to infants' behavior and preferences. With these macrolevel constraints, we were then better able to assess how microlevel changes in design context (i.e., stimulus characteristics, stimulus presentation, and randomized or blocked designs) affected infant behavior. We also examined how their behavioral patterns and potential attractor states varied across the testing session.

Examining the overall variability in infant behavior across ages and contexts helped us understand if infants had different patterns of looking (regardless of the content of their preferences) when they saw particular face pairs or if the stability of looking differed between younger and older infants. We anticipated that infants would show higher dispersion and visit entropy (i.e., more variable and less predictable looking patterns, respectively) when viewing unfamiliar race face pairs than when viewing familiar race face pairs. Younger infants should have lower dispersion and visit entropy than older infants because younger infants do not typically engage in as many comparative looks during a single trial as older infants (Rose, Feldman, & Jankowski, 2002). Examining changes in variability across trials helped us understand whether and how infants' behavior changed due to cumulative experience with faces during the testing session, and how they responded to the contextual aspects of the randomized and blocked designs. We anticipated that on average, infants' variability would decrease from the beginning to the end of the testing session as they became more familiar with the novel testing environment. If infants were sensitive to the context of the blocked design, however, they might exhibit momentary periods of increased variability (i.e., higher dispersion and visit entropy) during the first trial of each block. Examining attractor strength and stability across trials should help us understand if infants' looking toward females and males changed during the course of the study, or if particular facial stimuli were stronger, more stable attractors for infants. For example, infants should experience the strongest, most stable attractor states when viewing familiar race females. Exploring infants' look away behavior might help us understand infants' attention during these tasks and could potentially inform research design for preference studies (i.e., if infants' look away behavior increases dramatically toward the end of the trials, studies may be too long and no longer maintain infant attention). Look away behavior could also provide information about infants' interest toward certain face types. For example, infants might show more interest (i.e., less look away behavior) toward high attractive face pairs as compared to other attractiveness levels.

We predicted that infants in both randomized and blocked conditions would exhibit preferences for familiar race females over familiar race males. When given a predictable context (race is blocked), however, infants might learn about novel race faces and respond differently toward the stimuli than in an unpredictable context (race is randomized). Therefore, we anticipated that infants in the blocked condition would be more likely to show preferences for unfamiliar race females than infants in the randomized condition.

Method

Participants. Infants participated in either a randomized ($N = 79$) or blocked ($N = 88$) condition. Infants aged 3 to 4 ($n = 36$, 21 girls; $M_{days} = 103.86$, $SD_{days} = 9.60$) and 9 to 10 ($n = 43$, 16 girls; $M_{days} = 284.95$, $SD_{days} = 8.44$) months participated in the randomized condition. Infants aged 3 to 4 ($n = 43$, 20 girls; $M_{days} = 103.95$, $SD_{days} = 8.74$) and 9 to 10 ($n = 45$, 20 girls; $M_{days} = 283.09$, $SD_{days} = 13.81$) months participated in the blocked condition. All infants had Caucasian, female primary caregivers. We recruited participants using a database of names that research assistants compiled using birth announcements found in local newspapers, lists of potential families from a marketing firm, or responses from social media advertisements. Research assistants then contacted families via phone or email to set up appointments. Data from an additional 50 infants were not included in analyses for the following a priori reasons: fussiness

(19), side preference of more than 90% looking toward one side across the testing session (13), preterm (born more than 21 days prior to the due date; 9), parental interaction (3), experimenter error (3), poor interrater reliability (2), and developmental, auditory, or visual delay (1). Families received a bib or t-shirt for participating.

Stimulus Faces. Stimulus faces consisted of 24 male and 24 female college-aged volunteers who self identified as non-Hispanic/White, Black/African American, Asian/Asian American, or Spanish/Hispanic/Latino. All images were digitized, color photos of faces from the neck up with neutral expressions. Researchers masked clothing cues and adjusted all images using Adobe Photoshop software to be similar in image size, brightness, and contrast. Independent groups of at least 40 undergraduates rated faces for attractiveness using a 5-point scale ranging from 1 (*not very attractive*) to 5 (*very attractive*). Interrater agreement was high (*alphas* > .95). Researchers chose faces based on attractiveness ratings and divided face pairs into low, medium, and high attractive groups. All face pairs matched in attractiveness, age, race, and hair color. Female faces ($M = 2.21$, $SD = 0.69$) did not differ in attractiveness from male faces ($M = 2.23$, $SD = 0.63$, $t(23) = 0.59$, $p = .56$). High attractive faces ($M = 2.97$, $SD = 0.39$) differed from medium attractive faces ($M = 2.17$, $SD = 0.17$, $t(15) = 10.39$, $p < .001$), and medium attractive faces differed from low attractive faces ($M = 1.51$, $SD = 0.17$, $t(15) = 9.35$, $p < .001$). We created two sets of stimuli (sets A and B), each containing 12 female-male face pairs with three pairs (one low, one medium, and one high attractive) from each racial/ethnic group.

Apparatus. The parent and child sat on one side of a partition approximately 61 cm (for 3-month-olds) or 127 cm (for 9-month-olds) away from two, 43.18 cm computer monitors that were level with the infant’s eyes. A black, wooden structure housed the two monitors, which were 30.5 cm apart. A camera located behind the parent and child recorded the two monitors to ensure the proper stimuli displayed during the study. The experimenter sat on the other side of the partition and controlled the study using a computer with Habit X 1.0 software (Cohen, Atkinson, & Chaput, 2004). The experimenter monitored the child via a digital video camera connected to a TV. The digital video camera was located below the two computer monitors and recorded the child’s looking behavior so that research assistants could later code the duration and number of looks toward each monitor using Supercoder software (Hollich, 2005).

Procedure. The experimenter explained the study to the parent and obtained informed consent and voluntary demographic information. During the study, the infant sat on the parent’s lap in a darkened room. The experimenter requested the parent not interact with the child. The parent wore opaque sunglasses to ensure that the parent’s interest in the faces did not influence the child’s preferences.

Infants were randomly assigned to a randomized or blocked condition and saw stimulus set A or B. To start the study and between each trial, experimenters played a brief attention getter (a growing and shrinking green ball paired with a whistle sound) until infants directed their attention toward the monitors. All infants saw twelve, 10 s test trials. Each test trial consisted of a male and female face pair that matched in race/ethnicity and attractiveness level. Infants in the blocked condition saw face pairs blocked by race in which the high, medium, and low attractive face pairs from a particular race were blocked together with attractiveness level randomized within each block. Race blocks were randomized across infants. For the randomized condition, infants saw face pairs that varied in race and attractiveness level with the constraint that no more than two face pairs of the same race/ethnicity appeared across consecutive trials. For both the randomized and blocked designs, the left-right position of male and female faces was counterbalanced across trials.

Data coding. Two to three trained research assistants coded infant looking time data using offline digitized videos of each infant. Research assistants slowed down videos to record frame-by-frame (1/30 s) the onset and offset time for each look toward a stimulus monitor (i.e., left or right looks). We then assessed coder reliability for looking time (M_{ICC} = .973, range .831 - .999) during each trial. Once we assessed reliability, we used the most reliable coder's data for analyses. For data used to create variables for the traditional infant looking time analyses, we rounded looking time to the nearest 100 ms.

For data used to create SSG variables, we created sequential series of onset and offset time intervals rounded to the nearest 100 ms. We chose 100 ms as a minimum time interval because it is a time frame often used in infant eye-tracking research to denote the shortest possible fixation time (e.g., Gredebäck & von Hofsten, 2004) and to avoid coding look away data for single-frame intervals when the infant switched between stimuli without looking away from the monitors. Time intervals consisted of the duration of each look toward stimulus A, stimulus B, or away. We created individual sequences (i.e., trajectories) for each trial. Hollenstein (2013) recommends dividing data into the smallest unit possible and then using grouping variables within the GridWare program to aggregate data if desired. Because our data contain only one state variable (i.e., looking time), we created a lagged phase plot (i.e., the autocorrelation of data at time *t* on the x-axis with itself at *t* + 1 on the y-axis) to construct a complete phase space (e.g., Heath, 2000, Hollenstein, 2013). The lagged phase plot consisted of a single-trial trajectory sequence plotted against its sequence with a lag of one event, so that each cell in the SSG corresponded to a potential transition sequence (see Figure 3 for a sample trajectory, its lagged sequence trajectory, and resulting lagged phase plot). If the final look for each sequence was toward one of the stimulus faces, we plotted the look against itself because the infant did not “choose” to look away (see the final look on the lagged trajectory of Figure 3). If the infant looked away when a trial ended, then we coded the final look as “away” to “away”. Coding the final look in this manner allowed us to maintain a constant trajectory length for each trial and ensure we captured the duration of all looks.

Original Trajectory	
Onset Time (ms)	**Look**
0	Male
400	Female
2100	Male
3500	Away
3700	Female
4600	Male
7500	Female
9100	Male
9700	Female
10400	

Lagged Trajectory		
Onset Time (ms)	**Look**	**Look(t+1)**
0	Male	Female
400	Female	Male
2100	Male	Away
3500	Away	Female
3700	Female	Male
4600	Male	Female
7500	Female	Male
9100	Male	Female
9700	Female	Female
10400		

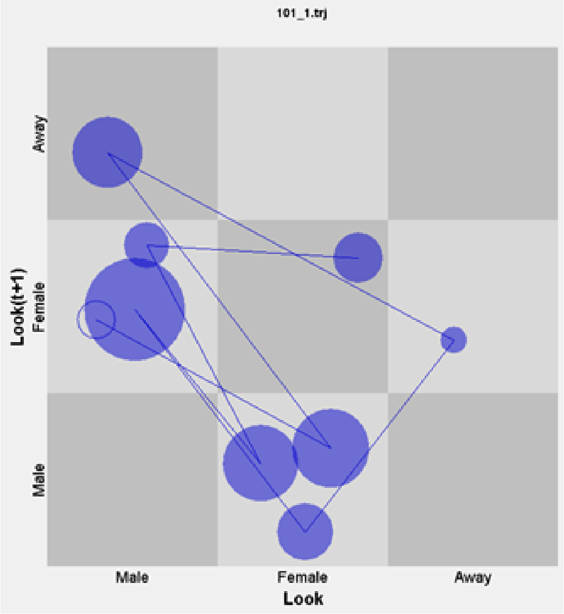

Figure 3. Sample trajectory sequence, lagged trajectory sequence, and resulting state space grid (SSG) for an infants’ looking toward a male and female face during one 10.4 s trial.

Variables.

Traditional infant looking time analyses. We calculated infants' looking time and number of looks toward each stimulus face for each trial. We then calculated the percentage of total looking time (PTLT) toward the female face for each trial by taking the total time looking toward the female face divided by the total time looking toward both faces.

Dynamic systems perspective analyses.

Whole-grid variables. We divided each infant's data into trials and used each trial as a separate trajectory for analyses. For each trajectory we calculated the whole-grid variables of dispersion and visit entropy (see Table 1).

Attractor identification. Because our looking data had so few potential states (i.e., stimulus A, stimulus B, away), we identified potential attractors theoretically and used a measure of attractor strength for our analyses. A variety of potential variables exist for measuring attractor strength (Hollenstein, 2013), so we explored some options to determine the best way to identify attractor strength for infant looking time data. We selected regions in the state space that corresponded to each potential look. We examined the region-specific variables of return time, first entry, last exit, and mean duration per visit but found them to be problematic because they either resulted in a dramatic loss of data (e.g., for 3-month-olds in the randomized condition of Experiment 1, using last entry would have resulted in data reduction of 28%) or they were not appropriate for a design with short time intervals. For example, Hollenstein (2013) suggested using return time in instances when trajectories return to attractors frequently, but in 10 or 15 s trials, infants often provided few looks or transitions to previous states. We also found variables that involved the number and frequency of visits or duration information to be problematic because they were either skewed or kurtotic (particularly in the case of number of visits) or could potentially produce biased results because duration of stimulus presentation was not consistent across all trials and participants (i.e., due to computer processing some infants saw stimuli for slightly longer times than others). For these reasons we chose to use the proportion of time in each state. Although this variable is very similar to percentage of total looking time, it better accounts for all potential attractor states of the preferential looking system (i.e., infants may have a strong look away attractor, which is not accounted for with the PTLT variable).

Data Analyses

Traditional infant looking time analyses. Developmental researchers frequently use percentage of total looking time (PTLT) for examining data acquired during VPC paradigms. Mean PTLT is examined either by comparing groups in an analysis of means or comparing mean PTLT to chance (50%) performance. Because of its frequent (almost exclusive) use in the infant literature, mean PTLT served as our primary measure for traditional analyses. For both the randomized and blocked conditions, we conducted separate 2 x 2 x 3 (Infant Age [3 months, 9 months] x Race Familiarity [familiar, unfamiliar] x Attractiveness [low, medium, high]) SAS proc mixed analyses with repeated measures. For each condition, we first compared model fit statistics for a model with race (African American, Asian, Caucasian, Latino) or race familiarity (familiar, unfamiliar) as the grouping variable for race of stimulus faces, and in both instances race familiarity provided a better fit to the data as indicated by lower Akaike information criterion (AIC), and Bayesian information criterion (BIC) fit indices (SAS Institute, 2011). We also compared models that included infant sex and race order (i.e., the first, second, or third instance an infant saw a particular race face) and chose the model that provided the best fit and included significant effects and interactions involving all potential independent variables. For the randomized condition, the best fitting model was the 2 x 2 x 3 (Infant Age x Race Familiarity x

Attractiveness) model, and for the blocked condition the best fitting model was the 2 x 2 x 3 x 3 (Infant Age x Race Familiarity x Attractiveness x Race Order) model. For all significant effects and interactions we compared least-squares means (*LSM*) using Tukey-Kramer adjustments. Finally, we followed up significant group differences by comparing least-squares means to chance (50%) and corrected for multiple *t*-tests using the Benjamini and Hochberg (2000) adaptive false discovery rate.

Dynamic systems perspective analyses.

Overall variability. We examined the data using the whole-grid variables of dispersion and visit entropy to assess variability of infant behavior. We examined potential group differences in variability by conducting separate SAS proc mixed analyses for dispersion and visit entropy using the same grouping variables as those used for the traditional looking time analyses. Again, we started with the base 2 x 2 x 3 (Infant Age x Race Familiarity x Attractiveness) model and compared fit indices of models including infant sex and race order. For the randomized condition, the base model provided the best fit to the data. For the blocked condition, infant sex and race order also produced significant interactions for dispersion which resulted in a 2 x 2 x 2 x 3 x 3 (Infant Age x Infant Sex x Race Familiarity x Attractiveness x Race Order) SAS proc mixed analysis. For visit entropy a 2 x 2 x 3 x 3 (Infant Age x Race Familiarity x Attractiveness x Race Order) SAS proc mixed analysis provided the best fit and included all significant variables.

Changes in variability. Because the data were divided into individual trajectories for each trial, we conducted growth curve analyses using hierarchical linear modeling to assess the change in variability across time separately for dispersion and visit entropy. First we calculated intraclass correlation coefficients (ICC) without predictors to determine whether there was sufficient variation among infants' dispersion, $\text{ICC}_{\text{random}} = .49$, $\text{ICC}_{\text{block}} = .43$, and visit entropy scores, $\text{ICC}_{\text{random}} = .47$, $\text{ICC}_{\text{block}} = .42$, and concluded that growth curve analyses were appropriate for each variable in both the randomized and blocked conditions. We then proceeded with model building. First, we compared models with linear, quadratic, and cubic terms and chose the best fitting model. Second, we added the level-1, time-varying predictors of race familiarity, Race Familiarity x Time, attractiveness, and Attractiveness x Time. We then compared model fit among significant level-1 models with random and fixed effects. Finally, we added the level-2 predictors of infant age and sex to the best fitting model from the previous step and again compared model fit for random and fixed effects. Because all predictors were categorical or ordinal, variables were dummy coded such that zero values reflected familiar race faces, low attractive faces, 3-month-old infants, and female infants for the variables of race familiarity, attractiveness, infant age, and infant sex, respectively. For model comparison, we estimated models using HLM7 software (Raudenbush, Bryk, Cheong, Congdon, & Du Toit, 2011) with full information maximum likelihood (FIML) estimation and compared nested models using the likelihood ratio test of deviance scores (-2LL) and unnested models using AIC and BIC values. Our goal was to determine the best fitting, most parsimonious model for each variable.

Attractor stability. We assessed attractor stability by measuring the relative strength of each attractor state for each trial by calculating the proportion of time infants spent in each state. We then conducted three separate growth curve analyses to assess the stability of each attractor (female proportion, male proportion, and away proportion) across trials. We followed the same model building procedure as that done to assess changes in stability. First we calculated intraclass correlation coefficients (ICC) without predictors to determine if the variation among the attractor states of female proportion, male proportion, and away proportion was sufficient to proceed with HLM analysis. The ICCs for female proportion, ICC_{random} = .04, ICC_{block} = .04, and male proportion, ICC_{random} = .01, ICC_{block} = .04, were fairly low indicating that sufficient variability might not exist among infants to warrant HLM analysis. In all four instances, however, the variance components for the intercepts were significant, which meant that the ICCs were significant and HLM analysis was appropriate (Garson, 2012). The ICCs for away proportion, ICC_{random} = .37, ICC_{block} = .43, indicated that variance among individuals was sufficient for HLM analysis. Next, we followed the same, three-step model building process as that for assessing changes in variability. At the second step, however, we also included the potential level-1 predictors of dispersion, Dispersion x Time, visit entropy, and Visit Entropy x Time. Dispersion and visit entropy were continuous variables with meaningful zeros, so effects involving these variables reflect one-unit changes in either dispersion or visit entropy.

Results

Randomized condition.

Traditional infant looking time analyses. Results for the PTLT analysis revealed a main effect for attractiveness, $F(2,154) = 6.07$, $p = .003$, $\omega^2 = .011$, and a marginally significant main effect for infant age, $F(1,77) = 3.69$, $p = .058$, $\omega^2 = .003$. Both main effects were superseded by a significant Infant Age x Attractiveness interaction, $F(2,154) = 3.69$, $p = .027$, $\omega^2 = .006$. A comparison of least-squared means revealed that 3-month-olds had significantly higher PTLT toward female faces when viewing low attractive face pairs than when viewing medium attractive or high attractive face pairs, *p*s < .05. Three-month-olds also had significantly higher PTLT toward females when viewing low attractive face pairs than 9-month-olds had toward females when viewing face pairs from any attractiveness level, *p*s < .05. Comparing PTLT toward female faces to chance (50%) revealed that 3-month-olds looked toward females significantly greater than chance when viewing low attractive face pairs, $t(849) = 5.28$, $p < .001$. See Table 2 for means and standard errors for the Infant Age x Attractiveness interaction.

Results also revealed a significant Race Familiarity x Attractiveness interaction, $F(2,150) = 3.18$, $p = .044$, $\omega^2 = .005$. A comparison of least-squares means revealed that when infants viewed familiar race, low attractive face pairs their PTLT toward females was significantly greater than their PTLT toward females when viewing familiar race, high attractive face pairs and unfamiliar race medium and high attractive face pairs, *p*s < .05. Only the PTLT for familiar race, low attractive female faces significantly differed from chance looking, $t(849) = 4.23$, $p < .001$. See Table 2 for means and standard errors for the Race Familiarity x Attractiveness interaction. See Appendix A: Table 21 for a summary of significant results from Experiment 1.

Table 2

Least-squares Means and Standard Errors for Percentage of Total Looking Time (PTLT) in the Randomized Condition

	LS mean	(SE)
Infant Age x Attractiveness		
3-month – low	.66***	(.03)
3-month – medium	.53	(.03)
3-month – high	.49	(.03)
9-month – low	.53	(.03)
9-month – medium	.50	(.03)
9-month – high	.52	(.03)
Race Familiarity x Attractiveness		
familiar race – low	.65***	(.04)
familiar race – medium	.53	(.04)
familiar race – high	.49	(.04)
unfamiliar race – low	.54	(.02)
unfamiliar race – medium	.50	(.02)
unfamiliar race – high	.52	(.02)

*** $p < 0.001$, significantly differs from chance (50%)

Dynamic systems perspective analyses.

Overall variability. Results for the SSG analyses revealed significant main effects for infant age for both dispersion, $F(1,77) = 330.59$, $p < .001$, $\omega^2 = .240$, and visit entropy, $F(1,77) = 279.53$, $p < .001$, $\omega^2 = .214$. In both instances 9-month-olds had significantly more dispersed looking behavior (i.e., higher dispersion, $LSM = .74$, $SE = .01$) and less predictable looking patterns (i.e., higher visit entropy, $LSM = 1.51$, $SE = .02$) than 3-month-olds ($LSM = .42$, $SE = .01$, $LSM = 0.94$, $SE = .01$, respectively). These results indicated that, overall, 9-month-olds had higher variability in their behavior (i.e., behavior that was more dispersed in the frequency and duration of looks and had less predictable patterns of looking and transitions between and away from face pairs) than 3-month-olds.

Changes in variability. For dispersion the unconditional model with only a linear term provided the best fitting growth model; no level-1 predictors contributed to the model, but infant age was a significant level-2 predictor with random effects on the intercept and slope. See Table 3 for a comparison between the unconditional and best fitting conditional models and Figure 4 for an illustration of individual variability in intercepts and slopes. The average 3-month-old had an initial dispersion of .35, and the average 9-month-old had an initial dispersion of .71. On average, 3-month-olds' dispersion increased by .01 across consecutive trials, and 9-month-olds' dispersion decreased by .003 across consecutive trials. By the end of the study, the average 3-month-old's dispersion increased to .50, whereas the average 9-month-old's dispersion decreased to .67. These results indicated that initially 3-month-olds had less variability (i.e., shorter and/or less frequent looks) in the looking behavior than 9-month-olds, but across trials 3-month-olds' looking behavior became more variable, whereas 9-month-olds' variability decreased slightly. These patterns, however, reflected average effects. As the significant random variance components and Figure 4 suggested, individual infants exhibited a variety of alternative trajectories including some 3-month-olds engaged in looking patterns more similar to the average 9-month-old (i.e., looking that was initially fairly variable and decreased in variability across trials).

After controlling for age, the correlation between initial dispersion scores and the rate of change in dispersion was -.67 ($p < .01$) indicating that infants with lower dispersion scores on Trial 1 showed a faster rate of increase in dispersion across trials than did infants with higher initial dispersion. These results indicated that, regardless of age, infants who had low variability in their looking behavior (i.e., few looks across cells and/or long looks) at the beginning of the study had a more rapid increase in variability across trials than infants who initially had high variability (i.e., more frequent and/or shorter looks).

Table 3

Growth Model Comparison for Dispersion for the Randomized Condition

	Unconditional Model			Conditional Model		
Fixed Effects	*Coef. (SE)*	*t (df)*	*p*	*Coef. (SE)*	*t (df)*	*p*
Intercept (β_{00})	.574 (.031)	18.55 (78)	<.001	.354 (.031)	11.33 (77)	<.001
by Age (β_{01})				.403 (.042)	9.52 (77)	<.001
Time (β_{10})	.004 (.003)	1.40 (78)	.165	.013 (.004)	3.33 (77)	.001
by Age (β_{11})				-.016 (.005)	-3.15 (77)	.002
Random Effects *(Var. Components)*	*Variance*	χ^2 *(df)*	*p*	*Variance*	χ^2 *(df)*	*p*
Intercept (r_{0i})	.065	580.49 (78)	<.001	.025	270.68 (77)	<.001
Time (r_{1i})	.0003	190.29 (78)	<.001	.0003	169.00 (77)	<.001
Level-1 (e_{ti})	.035			.035		
				Variance Explained		
				Intercept	61.81%	
				Time	17.65%	
				Level-1	0%	

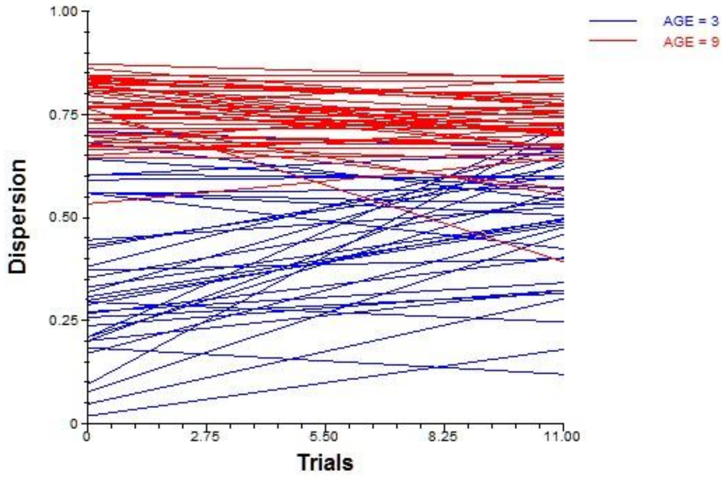

Figure 4. Individual level-1 line equations for dispersion for infants in the randomized condition.

The growth model for visit entropy was very similar to dispersion. Again, the unconditional linear model provided the best fitting growth model; no level-1 predictors contributed to the model, but infant age was a significant level-2 predictor with random effects on the intercept and slope (see Table 4 and Figure 5). As with dispersion, the average 3-month-old initially had lower visit entropy (i.e., fewer and/or more predictable looks) than the average 9-month-old, and the average 3-month-olds' visit entropy increased across trials (i.e., their looking became less predictable involving more looks and transitions), whereas the average 9-month-olds' looking became slightly more predictable across trials.

After controlling for age, the correlation between initial visit entropy and the rate of change in visit entropy was -.67 (*p* < .01). This correlation indicated a similar pattern as dispersion in that, regardless of age, infants with lower initial visit entropy showed a faster rate of change across trials than did infants with higher initial visit entropy. These results indicated that infants who had more predictable patterns of looking at the beginning of the testing session (e.g., only one or two looks or transitions during Trial 1) showed a more rapid increase in their looking behavior (i.e., more looks and more transitions per trial) than did infants who started out with less predictable patterns of looking (i.e., many looks with multiple transitions between and away from the stimulus faces).

Table 4

Growth Model Comparison for Visit Entropy for the Randomized Condition

	Unconditional Model			Conditional Model		
Fixed Effects	*Coef. (SE)*	*t (df)*	*p*	*Coef. (SE)*	*t (df)*	*p*
Intercept (β_{00})	1.205 (.058)	20.63 (78)	<.001	0.811 (.085)	9.55 (77)	<.001
by Age (β_{01})				0.724 (.090)	8.03 (77)	<.001
Time (β_{10})	0.009 (.005)	1.64 (78)	.106	0.025 (.010)	2.52 (77)	.014
by Age (β_{11})				-0.029 (.011)	-2.77 (77)	.007
Random Effects						
(Var. Components)	*Variance*	*χ^2 (df)*	*p*	*Variance*	*χ^2 (df)*	*p*
Intercept (r_{0i})	0.230	542.79 (78)	<.001	0.100	281.21 (77)	<.001
Time (r_{1i})	0.001	184.47 (78)	<.001	0.001	166.33 (77)	<.001
Level-1 (e_{ti})	0.133			0.133		
				Variance Explained		
				Intercept	56.46%	
				Time	16.94%	
				Level-1	0%	

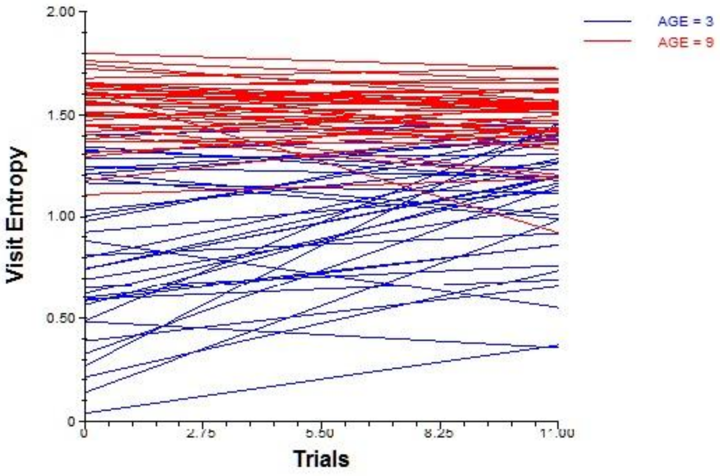

Figure 5. Individual level-1 line equations for visit entropy for infants in the randomized condition.

Attractor stability. For the female attractor state (i.e., female proportion) the best fitting model did not include a time component which suggested that, on average, the proportion of time infants looked toward females did not change across trials (e.g., no steady increase, deceleration, or systematic increase then decrease). Attractiveness and dispersion significantly contributed to the model at level-1, and at level-2, infant age significantly affected the intercept, attractiveness, and dispersion (see Table 5 for the best fitting model). Results indicated that the average 3-month-old with 0 dispersion had a female proportion of .60 when viewing low attractive face pairs. As 3-month-olds' dispersion increased (i.e., behavior became more variable with more frequent and/or shorter looks) the proportion of time they spent looking toward females decreased. Nine-month-olds with 0 dispersion had an average female proportion of .28 to low attractive face pairs, and as 9-month-olds' looking patterns increased (i.e., higher dispersion) their proportion of looking toward females increased. These results suggested that female faces might be different attractor states for younger and older infants. The more time 3-month-olds attended to females, the less variable their behavior, which suggests that female faces might be a strong and stable attractor that was difficult for younger infants to escape. On the other hand, the more 9-month-olds attended to females, the more variable their behavior, which suggests that even though female faces might have still been a strong attractor state for older infants, they were a little less stable, which allowed older infants to transition among attractor states in a more flexible manner.

When the attractiveness of face pairs increased, 3-month-olds' female proportion decreased by about .06 and 9-month-olds' female proportion decreased by about .004. On average, 3-month-olds showed significant decreased looking toward medium and high attractive females (as compared to low attractive females), which indicated that low attractive female faces were strong attractors for younger infants. On the other hand, 9-month-olds' looking toward females was relatively stable across all three attractiveness levels.

For the male attractor state (i.e., male proportion) the best fitting model also did not include a time component but did include attractiveness as a level-1 predictor, and infant age significantly contributed to attractiveness (see Table 5). Results indicated that on average infants' male proportion was .35 when viewing low attractive face pairs, but as attractiveness level increased, 3-month-olds' male proportion increased by about .05 and 9-month-olds' male proportion increased by about .0003. These results suggested 3- and 9-month-olds looked to low attractive males for similar proportions of time, but as the attractiveness of face pairs increased 3-month-olds looked more toward males (i.e., high attractive males were stronger attractor states for younger infants), whereas 9-month-olds' looking to males was relatively stable across attractiveness levels.

Table 5

Best Fitting Growth Models for the Attractor States of Female Proportion and Male Proportion for the Randomized Condition

	Female Proportion			Male Proportion		
Fixed Effects	*Coef. (SE)*	*t (df)*	*p*	*Coef. (SE)*	*t (df)*	*p*
Intercept (β_{00})	.603 (.034)	17.62 (77)	<.001	.352 (.016)	22.68 (78)	<.001
by Age (β_{01})	-.323 (.074)	-4.35 (77)	<.001			
Attractiveness (β_{10})	-.058 (.020)	-2.97 (77)	.004	.0469 (.016)	2.95 (77)	.004
by Age (β_{11})	.054 (.026)	2.03 (77)	.046	-.0466 (.016)	-2.94 (77)	.004
Dispersion (β_{20})	-.168 (.050)	-3.38 (77)	.001			
by Age (β_{21})	.285 (.096)	2.96 (77)				
Random Effects (Var. Components)	*Variance*	*χ^2 (df)*	*p*	*Variance*	*χ^2 (df)*	*p*
Intercept (r_{0i})	.010	119.24 (77)	.002	.003	92.91 (78)	.120
Attractiveness (r_{1i})	.004	114.21 (77)	.004	.004	114.73 (77)	.004
Dispersion (r_{2i})	.007	100.67 (77)	.036			
Level-1 (e_{ti})	.077			.077		
	Variance Explained			*Variance Explained*		
Intercept	64.92%			0%		
Attractiveness	10.33%			14.09%		
Dispersion	71.84%					
Level-1	0%			0%		

For the look away attractor state (i.e., away proportion) the best fitting model included a linear component, which indicated that unlike the attractor states for looking toward females and males, infants' proportion of looking away systematically changed across trials. Dispersion was a significant predictor at level-1, which indicated that infants' proportion of looking away was related to their overall patterns of looking (i.e., variability) across trials. Infant age had a significant effect on the intercept only (see Table 6 and Figure 6). The conditional model indicated that initially 9-month-olds had a higher proportion of looking away than 3-month-olds, but infants showed an average increase in away proportion of about .007 across consecutive trials regardless of age. Not surprisingly, as infants' dispersion increased (i.e., more variable behavior with shorter and/or more frequent looks and transitions) so did their proportion of time spent looking away. These results suggested that 9-month-olds spent a larger proportion of time looking away than did 3-month-olds. Both age groups gradually increased the amount of looking away across trials, and, when infants’ looking patterns were more varied, they also spent a larger proportion of time looking away.

Table 6

Growth Model Comparison for Away Proportion for the Randomized Condition

	Unconditional Model			Conditional Model		
Fixed Effects	*Coef. (SE)*	*t (df)*	*p*	*Coef. (SE)*	*t (df)*	*p*
Intercept (β_{00})	.167 (.019)	8.77 (78)	<.001	.074 (.047)	1.60 (77)	.113
by Age (β_{01})				.093 (.024)	3.87 (77)	<.001
Time (β_{10})	.008 (.002)	3.53 (78)	<.001	.007 (.002)	3.17 (78)	.002
Dispersion (β_{20})				.090 (.051)	1.76 (78)	.082
Random Effects (Var. Components)	*Variance*	χ^2 *(df)*	*p*	*Variance*	χ^2 *(df)*	*p*
Intercept (r_{0i})	.021	289.29 (78)	<.001	.107	340.82 (77)	<.001
Time (r_{1i})	.0003	190.43 (78)	<.001	.0002	173.06 (78)	<.001
Dispersion (r_{2i})				.121	236.72 (78)	<.001
Level-1 (e_{ti})	.026			.022		
				Variance Explained		
				Intercept	0%	
				Time	15.38%	
				Level-1	16.77%	

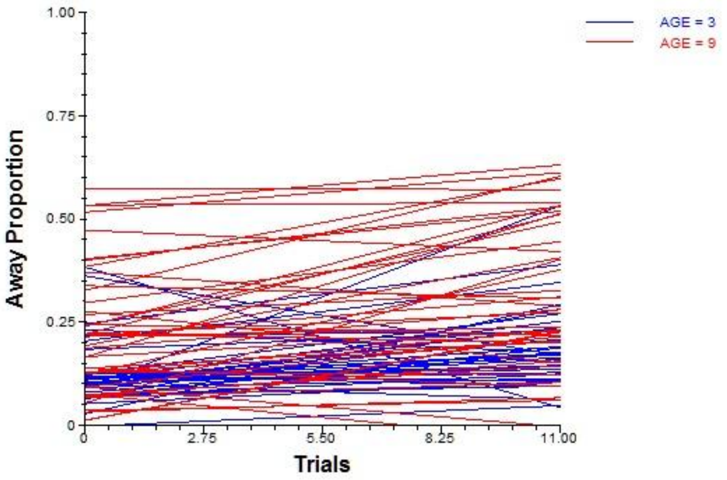

Figure 6. Individual level-1 line equations for away proportion for infants in the randomized condition. Other predictors in the model (i.e., dispersion) were held constant at the mean.

Blocked condition.

Traditional infant looking time analyses. Results for the PTLT analysis revealed a significant Infant Age x Race Familiarity x Attractiveness interaction, $F(2,172) = 3.83$, $p = .024$, $\omega^2 = .005$, and a marginally significant interaction for Infant Age x Race Order, $F(2,172) = 2.91$, $p = .057$, $\omega^2 = .004$. A comparison of least-squares means for the Infant Age x Race Familiarity x Attractiveness interaction revealed no significant differences among groups. Comparing PTLT toward female faces to chance, however, indicated that 3-month-olds who saw unfamiliar race, low attractive face pairs looked toward the female face significantly greater than chance, $t(172)$, = 3.41, $p < .01$. For the Infant Age x Race Order interaction, a comparison of least-squares means revealed no significant differences, and a comparison of PTLT to chance also revealed no significant differences. See Table 7 for means and standard errors for the Infant Age x Race Familiarity x Attractiveness interaction.

Table 7

Least-squares Means and Standard Errors for Percentage of Total Looking Time (PTLT) in the Blocked Condition

Infant Age x Race Familiarity x Attractiveness	LS mean	(SE)
3-month		
familiar race		
low attractive	.49	(.05)
medium attractive	.57	(.05)
high attractive	.46	(.05)
unfamiliar race		
low attractive	.59**	(.03)
medium attractive	.47	(.03)
high attractive	.51	(.03)
9-month		
familiar race		
low attractive	.54	(.05)
medium attractive	.45	(.05)
high attractive	.57	(.05)
unfamiliar race		
low attractive	.48	(.03)
medium attractive	.49	(.03)
high attractive	.51	(.03)

** $p < 0.01$ significantly differs from chance (50%)

Dynamic systems perspective analyses.

Overall variability. Results for the SSG measure of dispersion revealed significant main effects for infant age, $F(1,84) = 216.77$, $p < .001$, $\omega^2 = .150$, and race order, $F(2,168) = 3.49$, $p = .033$, $\omega^2 = .003$, and significant interactions including: Infant Age x Race Familiarity, $F(1,84) = 7.83$, $p = .006$, $\omega^2 = .005$; Infant Age x Race Order, $F(2,168) = 3.91$, $p = .022$, $\omega^2 = .004$; and Infant Sex x Race Order, $F(2,168) = 6.56$, $p = .002$, $\omega^2 = .008$. All main effects and interactions were superseded by two, 3-way interactions: Infant Age x Race Familiarity x Race Order, $F(2,168) = 4.79$, $p = .010$, $\omega^2 = .005$, and Infant Sex x Race Familiarity x Race Order, $F(2,168) = 3.48$, $p = .033$, $\omega^2 = .003$. Comparison of least-squares means for the Infant Age x Race Familiarity x Race Order interaction revealed that, in general, 9-month-olds had significantly higher dispersion (i.e., higher variability in looking patterns including shorter and/or more frequent looks) than 3-month-olds. There were, however, two exceptions: 3-month-olds' dispersion during the first and second trials of a familiar race block did not differ from 9-month-olds' dispersion on any familiar race trial. When 3-month-olds viewed familiar race face pairs, their dispersion significantly decreased (i.e., less variable looking patterns) from the first to the third trial. Finally, 3-month-olds' dispersion during the first two trials of the familiar race block was significantly higher than during the first trial of unfamiliar race blocks, *p*s $< .05$. See Figure 7 for all least-squares means and standard errors. These results indicated that, in almost all instances, 9-month-olds had more variable behavior patterns (i.e., shorter look durations and/or more frequent looks) than did 3-month-olds. Interestingly, 3-month-olds had a similar amount of variability during the first two trials of the familiar race block as 9-month-olds had during all familiar race trials. Three-month-olds had a significant decrease in the duration and frequency of their looking behavior from the first to the third trial of the familiar race block, which might indicate that they feel into a very stable state after a brief (i.e., two trial) period of seeing familiar stimuli. Lastly, 3-month-olds had higher variability during the first two trials of a familiar race block than during the first trial of an unfamiliar race block. Taken together these results might suggest that 3-month-olds are more susceptible to the blocked design than are 9-month-olds. Nine-month-olds' patterns of looking were relatively stable across all blocks and trials, whereas 3-month-olds' patterns of looking changed within and across blocks.

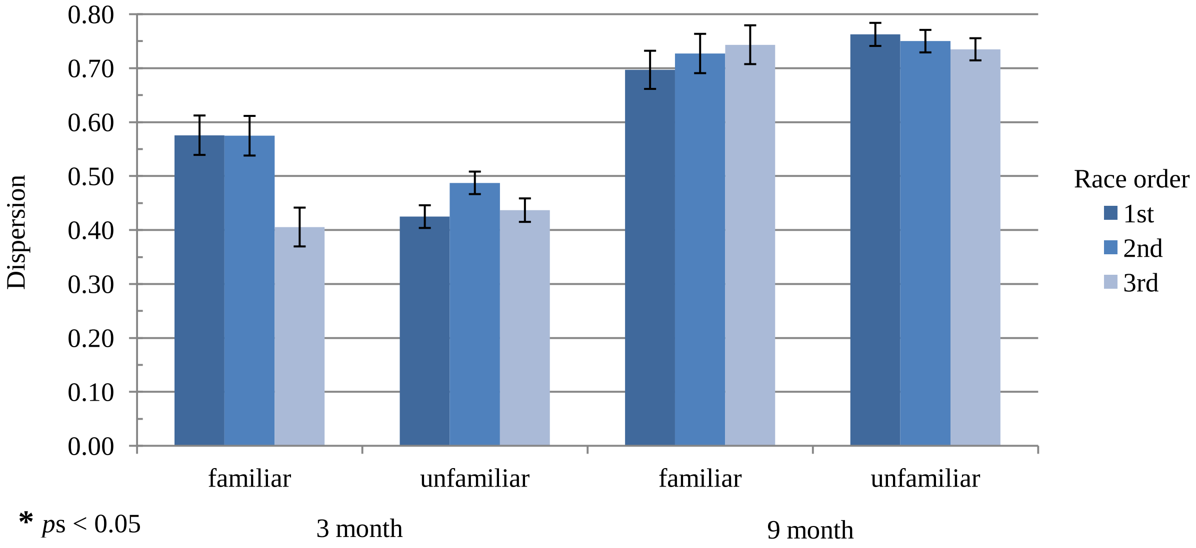

Figure 7. Least-squares means and standard errors for dispersion of infant behavior by age, race familiarity, and order of face-pair within familiar and unfamiliar race blocks. See text for significant results.

For the Infant Sex x Race Familiarity x Race Order interaction, a comparison of least-squares means revealed that when female infants viewed familiar race face pairs they had significantly higher dispersion during the second trial than the third trial. Also when viewing familiar race face pairs, female infants had significantly lower dispersion on the third trial than male infants had on the first trial, *p*s < .05. See Figure 8 for all least-squares means and standard errors. The results for female infants were similar to the results for 3-month-old infants; both groups showed a significant decrease in the variability of their looking patterns on the third trial of the familiar race block. Male infants showed relatively more stable patterns of looking within and across blocks than did female infants.

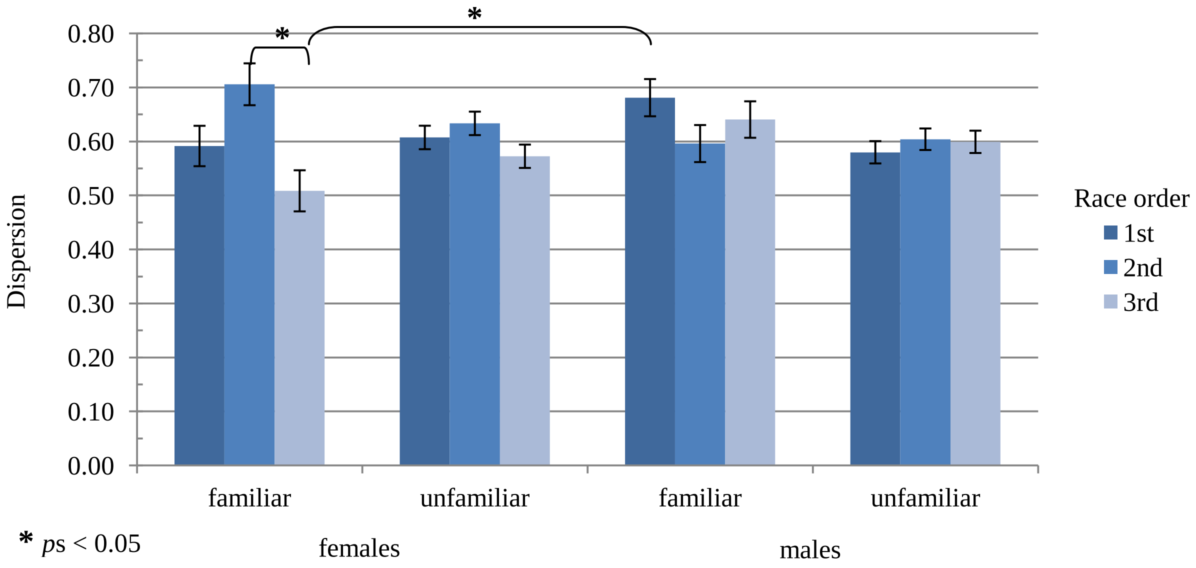

Figure 8. Least-squares means and standard errors for dispersion of infant behavior by infant sex, race familiarity, and order of face-pair within familiar and unfamiliar race blocks.

For the SSG measure of visit entropy, results revealed a significant main effect for infant age, $F(1,86) = 199.33$, $p < .001$, $\omega^2 = .145$, a significant interaction for Infant Age x Race Familiarity, $F(1,86) = 7.23$, $p = .009$, $\omega^2 = .005$, and a marginally significant interaction for Infant Age x Race Order, $F(2,172) = 2.98$, $p = .053$, $\omega^2 = .003$. For the Infant Age x Race Familiarity interaction, a comparison of least-squares means revealed that 9-month-olds had higher visit entropy (i.e., more looks and transitions between looks) than 3-month-olds regardless of the race familiarity of face pairs, *ps* < .05. Nine-month-olds had similar visit entropy when viewing familiar and unfamiliar race face pairs, $p > .05$, but 3-month-olds had higher visit entropy when viewing familiar race face pairs than when viewing unfamiliar race face pairs, *p* <

.05. See Figure 9 for least-squares means and standard errors for visit entropy broken down by age and race familiarity. These results indicated that 9-month-olds had more variable looking patterns (i.e., more looks and transitions and/or less predictable looking patterns) than 3-month-olds. Nine-month-olds' variability was similar across familiar and unfamiliar race blocks, whereas 3-month-olds had significantly more variability in looking during familiar race blocks than unfamiliar race blocks, which might suggest that the predictability of a familiar race blocked allowed younger infants to engage in more frequent looks and more transitions between and away from stimulus faces.

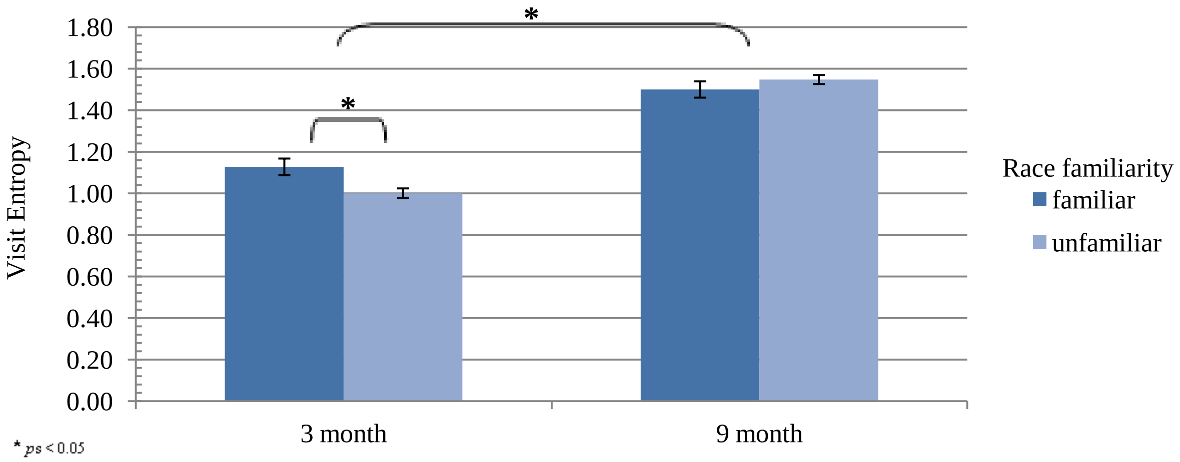

Figure 9. Least-squares means and standard errors for visit entropy of infant behavior by infant sex and race familiarity of face pairs.

A comparison of least-squares means for the Infant Age x Race Order interaction revealed that, again, 9-month-olds had significantly higher visit entropy than 3-month-olds regardless of the trial of a race block, *p*s < .05, but also that 3-month-olds had significantly lower visit entropy on the third trial of a race block than on the second trial of a race block, *p* < .05. Nine-month-olds had similar visit entropy across all trials of a race block, *p*s > .05. See Figure 10 for least-squares means and standard errors for visit entropy broken down by age and order of trials within race blocks. These results paralleled the results from dispersion. Three-month-olds showed a decrease in variability during the third trial of a race block (although for visit entropy, there was no difference related to race familiarity), and, in general, 9-month-olds had more variable (i.e., less predictable) looking patterns than 3-month-olds. Nine-month-olds' variability also appears to be stable across trials within a race block.

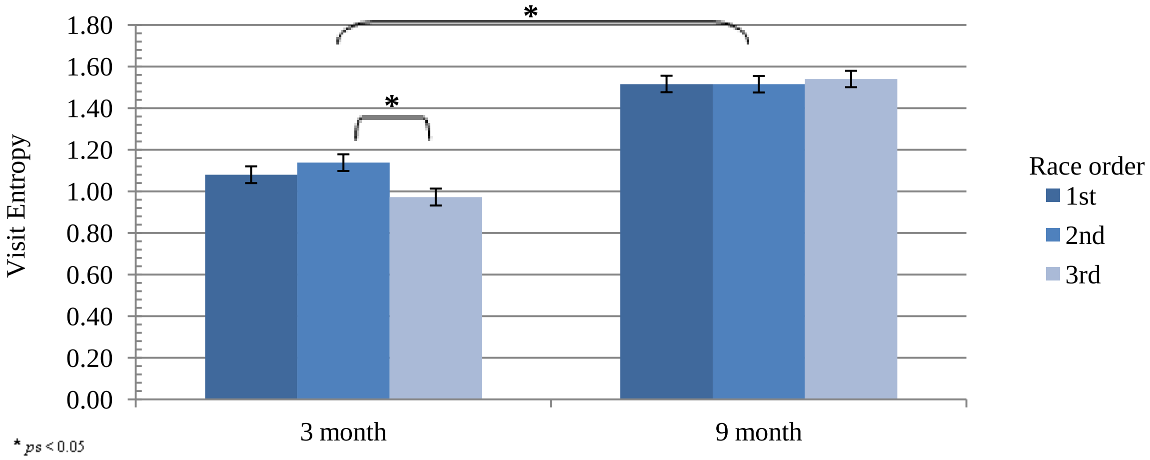

Figure 10. Least-squares means and standard errors for visit entropy of infant behavior by infant sex and order of face-pair within race blocks.

Changes in variability. The growth models for dispersion and visit entropy were very similar for the randomized and blocked conditions. As with the randomized condition, the best fitting models for dispersion and visit entropy in the blocked condition were ones with significant linear terms, no level-1 predictors, and infant age as a significant level-2 predictor with random effects on the intercepts and slopes (see Tables 8 and 9 and Figures 11 and 12). On average, 9-month-olds initially had higher variability (i.e., shorter looks, more frequent looks, and/or less predictable looking patterns) than 3-month-olds, and across trials 3-month-olds had a significant increase in variability, whereas 9-month-olds had a slight decrease in variability. Therefore, even though 3-month-olds tended to have looking behavior that reflected few looks, longer looks, and very predictable looking patterns at the beginning of the study, the variability of their looking patterns increased across trials and approached patterns more similar to 9-month-olds by the end of the study.

After controlling for age, the correlation between initial dispersion and the rate of change in dispersion was not significant, $r = -.47$, $p > .05$, but the intercept-correlation for visit entropy was significant, $r = -.60$, $p < .01$. For both variables, however, these correlations indicated the same pattern as the intercept-slope correlations for the randomized condition— regardless of age, infants who initially had lower variability in their looking patterns (i.e., fewer looks, longer looking durations, and/or more predictable patterns of looking) showed a more dramatic increase in variability across trials than did infants who initially had higher variability (i.e., shorter looks, more frequent looks, and/or less predictable looking patterns).

Table 8

Growth Model Comparison for Dispersion for the Blocked Condition

	Unconditional Model			Conditional Model		
Fixed Effects	*Coef. (SE)*	*t (df)*	*p*	*Coef. (SE)*	*t (df)*	*p*
Intercept (β_{00})	.606 (.025)	24.11 (87)	<.001	.439 (.026)	16.93 (86)	<.001
by Age (β_{01})				.327 (.036)	9.00 (86)	<.001
Time (β_{10})	.0008 (.002)	0.33 (87)	.739	.006 (.003)	1.89 (86)	.062
by Age (β_{11})				-.010 (.005)	-2.31 (86)	.023
Random Effects (Var. Components)	*Variance*	*χ^2 (df)*	*p*	*Variance*	*χ^2 (df)*	*p*
Intercept (r_{0i})	.044	424.73 (87)	<.001	.017	221.15 (86)	<.001
Time (r_{1i})	.0002	154.48 (87)	<.001	.0002	145.52 (86)	<.001
Level-1 (e_{ti})	.039			.039		
				Variance Explained		
				Intercept	60.49%	
				Time	14.29%	
				Level-1	0%	

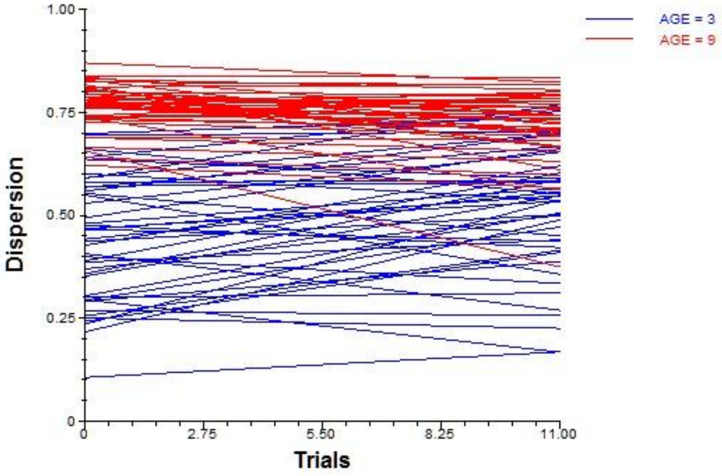

Figure 11. Individual level-1 line equations for dispersion for infants in the blocked condition.

Table 9

Growth Model Comparison for Visit Entropy for the Blocked Condition

	Unconditional Model			Conditional Model		
Fixed Effects	*Coef. (SE)*	*t (df)*	*P*	*Coef. (SE)*	*t (df)*	*p*
Intercept (β_{00})	1.251 (.049)	25.35 (87)	<.001	0.946 (.054)	17.53 (86)	<.001
by Age (β_{01})				0.596 (.076)	7.89 (86)	<.001
Time (β_{10})	0.007 (.005)	1.55 (87)	.124	0.017 (.008)	2.56 (86)	.012
by Age (β_{11})				-0.019 (.009)	-2.08 (86)	.046
Random Effects *(Var. Components)*	*Variance*	χ^2 *(df)*	*p*	*Variance*	χ^2 *(df)*	*p*
Intercept (r_{0i})	0.173	458.24 (87)	<.001	0.084	268.37 (86)	<.001
Time (r_{1i})	0.001	184.62 (87)	<.001	0.001	176.23 (86)	<.001
Level-1 (e_{ti})	0.139			0.139		
				Variance Explained		
				Intercept	51.31%	
				Slope	8.41%	
				Level-1	0%	

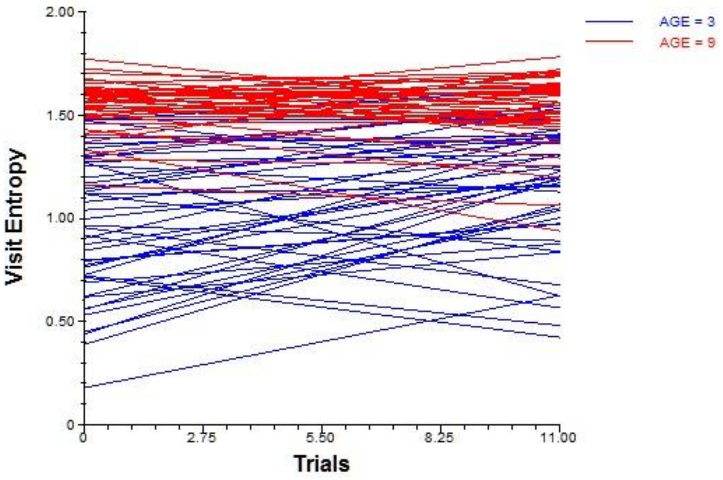

Figure 12. Individual level-1 line equations for visit entropy for infants in the blocked condition.

Attractor stability. For the female attractor state (i.e., female proportion) the best fitting model did not include a time component indicating that, on average, infants' looking toward females did not systematically change across trials. Dispersion significantly contributed to the model, and infant age significantly affected the intercept and dispersion (see Table 10 for the best fitting model). These results were very similar to the results for the female attractor from the randomized condition. On average, 3-month-olds had a higher proportion of looking toward females than 9-month-olds, and as 3-month-olds' looking patterns became more variable (i.e., higher dispersion), their looking toward females decreased, whereas increases in the variability of 9-month-olds' looking patterns lead to increased looking toward females.

For the male attractor (i.e., male proportion) the best fitting model did not include a time component, but including infant age accounted for some additional variance in the average proportion of looking toward males (see Table 10). Including visit entropy with random effects provided the best fitting model even though it was not a significant predictor in the final model.

Results indicated that, on average, 3-month-olds had a higher proportion of looking toward males than 9-month-olds, and as infants' visit entropy increased (i.e., looking patterns became less predictable), their looking toward males decreased (but not significantly so). These results indicated that, for all infants, male faces were a relatively stable attractor (not necessarily a strong attractor) across trials and contextual factors related to study design (e.g., attractiveness of face pairs and blocked orders of race familiarity).

Table 10

Best Fitting Growth Models for the Attractor States of Female Proportion and Male Proportion for the Blocked Condition

	Female Proportion			Male Proportion		
Fixed Effects	*Coef. (SE)*	*t (df)*	*p*	*Coef. (SE)*	*t (df)*	*p*
Intercept (β_{00})	.559 (.038)	14.85 (86)	<.001	.449 (.033)	13.45 (86)	<.001
by Age (β_{01})	-.222 (.081)	-2.74 (86)	<.001	-.043 (.020)	-2.10 (86)	.039
Dispersion (β_{10})	-.213 (.055)	-3.88 (86)	.004			
by Age (β_{11})	.238 (.108)	2.21 (86)	.030			
Visit Entropy (β_{20})				-.037 (.024)	-1.54 (87)	.127
Random Effects						
(Var. Components)	*Variance*	χ^2 *(df)*	*p*	*Variance*	χ^2 *(df)*	*p*
Intercept (r_{0i})	.032	148.93 (86)	<.001	.025	115.90 (86)	.017
Dispersion (r_{1i})	.044	118.81 (86)	.011			
Visit Entropy (r_{2i})				.009	92.76 (87)	.316
Level-1 (e_{ti})	.074			.077		
	Variance Explained			*Variance Explained*		
Intercept	25.29%			1.46%		
Dispersion	21.59%					
Visit Entropy				0%		
Level-1	0%			0%		

For the look away attractor (i.e., away proportion) the best fitting model was very similar to the model for the randomized condition. The model included a linear component and dispersion as a level-1 predictor. Infant age had a significant effect on the intercept and dispersion (see Table 11 and Figure 13). Results indicated that initially 9-month-olds had a higher proportion of looking away than 3-month-olds, but both ages had a linear increase in away proportion of about .007 across trials. For 3-month-olds, as dispersion increased, their away proportion also increased, but for 9-month-olds, as their dispersion increased, their away proportion decreased slightly. These results indicated that when 3-month-olds had more variability in their looking patterns, the look away attractor was stronger. On the other hand, when 9-month-olds had more variable behavior patterns, the look away attractor was weaker, indicating that older infants who were actively engaged in looking (i.e., more frequent and/or shorter looks) spent more time looking at the stimulus faces.

Table 11

Growth Model Comparison for Away Proportion for the Blocked Condition

	Unconditional Model			Conditional Model		
Fixed Effects	*Coef. (SE)*	*t (df)*	*p*	*Coef. (SE)*	*t (df)*	*p*
Intercept (β_{00})	.173 (.018)	9.38 (87)	<.001	.006 (.046)	0.13 (86)	.896
by Age (β_{01})				.268 (.075)	3.56 (86)	<.001
Time (β_{10})	.008 (.002)	3.51 (87)	<.001	.007 (.002)	3.40 (87)	.001
Dispersion (β_{20})				.194 (.050)	3.89 (86)	<.001
by Age (β_{20})				-.218 (.086)	-2.54 (86)	.013
Random Effects						
(Var. Components)	*Variance*	χ^2 *(df)*	*p*	*Variance*	χ^2 *(df)*	*p*
Intercept (r_{0i})	.023	377.55 (57)	<.001	.076	243.15 (86)	<.001
Time (r_{1i})	.0003	223.32 (87)	<.001	.0002	162.15 (87)	<.001
Dispersion (r_{2i})				.075	175.17 (86)	<.001
Level-1 (e_{ti})	.024			0.020		
				Variance Explained		
				Intercept	0%	
				Time	28.00%	
				Level-1	13.69%	

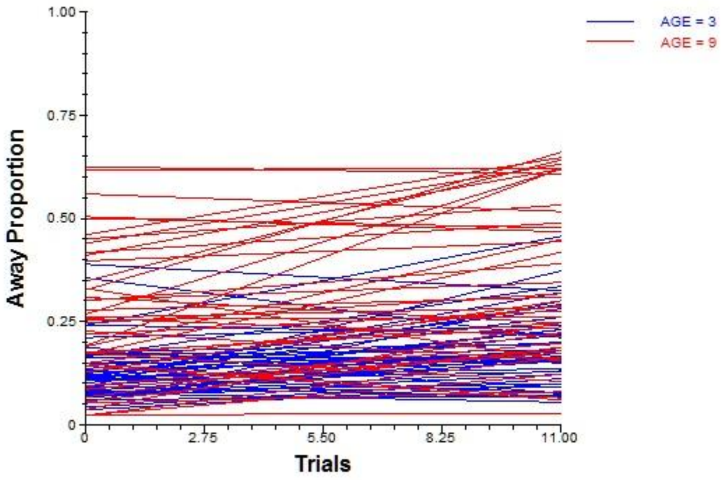

Figure 13. Individual level-1 line equations for away proportion for infants in the blocked condition. Other predictors in the model (i.e., dispersion) were held constant at the mean.

Discussion

From this investigation we discovered not only that infants exhibited group preferences for female faces in some instances but also that infants' looking behavior changed across trials and contexts. The variability and stability of infants' looking behavior varied across ages and, in the case of 3-month-olds, was dependent on characteristics of the facial stimuli (i.e., attractiveness level of face pairs) and the context of stimulus presentation (i.e., face pairs blocked by race). We found general linear trends in the variability of looking patterns among both 3- and 9-month-olds that suggest infants' behavioral patterns might have changed across trials due to adaptation to the testing environment and increased familiarity with the stimulus faces. By examining variability and attractor stability in addition to traditional looking time measures, it provided more insight into the processes underlying infants' looking behavior across different contexts.

Infants' preference for female faces over male faces exceeded chance levels only when infants viewed low attractive face pairs. For both the randomized and blocked conditions, infant age as well as the attractiveness and race familiarity of the face pairs influenced these preferences. In the randomized condition, infants showed a significant female preference when viewing low attractive, familiar race face pairs, and 3-month-olds showed a significant female preference when viewing low attractive face pairs in general. In the blocked condition, 3-month-olds showed a significant preference for females when viewing low attractive, unfamiliar race face pairs. The inclusion of analyses with a dynamic systems focus on changing patterns of behavior helped explain why these effects emerged and why other preferences might not have emerged.

Overall variability. By examining the overall variability of infant behavior we gained insights into how infants' patterns of looking were affected by the context of the design setting. As predicted we found that, in general, older infants had more variable patterns of looking than younger infants. In the randomized condition, 9-month-olds had more variable patterns of looking (i.e., higher dispersion and visit entropy) than 3-month-olds regardless of stimulus characteristics or presentation. In the blocked condition, however, the blocking of faces by race familiarity influenced infants' behavior patterns. In particular, when viewing familiar race faces, 3-month-olds and female infants showed a significant decrease in variability (i.e., dispersion) during the last trial of the block. Three-month-olds also had more predictable looking patterns (i.e., lower visit entropy) during the last trial of a race block. These results suggest that 3-month-olds and female infants might have fallen into very stable behavioral patterns after only a brief period (i.e., two trials) of familiarization with a race category, particularly when it was a category to which they had prior, real-world experience. These results somewhat support our prediction that infants would have more variability at the beginning of each race block, but suggest, however, that young infants might have noticed the transition to the familiar race block more than transitions to the unfamiliar race blocks. Three-month-olds' variability during trials 1 and 2 of the familiar race block was higher than their variability for the first trial of unfamiliar race blocks. Their variability during trials 1 and 2 of the familiar race block was also the only instance when 3-month-olds' variability was similar to 9-month-olds' variability. Three-month-olds in the blocked condition also exhibited fewer looks and transitions between stimuli (i.e., lower visit entropy) when viewing unfamiliar race faces than when viewing familiar race faces, and, in general, had lower dispersion and visit entropy than 9-month-olds.

The age related differences in behavioral patterns found in the blocked design suggest that 3-month-olds' visual preferences were more susceptible to changes in context (i.e., design manipulations) and subsequently, their looking patterns were more variable across trials with changing stimulus characteristics and presentation orders. On the other hand, 9-month-olds' patterns of looking remained stable across different contexts and were similar in both the randomized and blocked designs (i.e., average dispersion was about .75 and average visit entropy was about 1.50 for 9-month-olds in both conditions).

Interestingly, we did not find the predicted effect that infants would have more variability in their looking patterns when viewing unfamiliar race faces than when viewing familiar race faces. Race familiarity only influenced looking patterns during the blocked condition and had the most significant impact on 3-month-olds' behavior. Three-month-olds tended to show the opposite effect (i.e., low variability when looking at unfamiliar race faces). This pattern suggested that rather than engaging in chaotic, unpredictable patterns when looking at unfamiliar races, 3-month-olds engaged in very few looks and/or transitions between faces, which resulted in lower levels of variability. The unfamiliarity of such stimuli might have hindered 3-month-olds' ability to engage in comparative processing because they first had to process faces individually and did not have time to make comparisons between faces (e.g., Liu et al., 2015b). We did not find any differences among the variability patterns of 9-month-olds that were related to characteristics of the stimulus faces. Nine-month-olds have more cumulative experience with familiar race faces and female faces, therefore these face types should be particularly easy for them to process, and we would expect their patterns of looking toward these face types to be more stable and predictable than to unfamiliar race faces. It could be that our measure of variability was not sensitive enough to detect this effect (i.e., Figures 7 and 9 would suggest 9-month-olds' variability for familiar race faces was slightly lower than for unfamiliar race faces). Perhaps 9-month-olds exhibited different sequences of looks when looking at familiar versus unfamiliar races (e.g., looking between faces when viewing familiar races and looking between and away from faces when viewing unfamiliar races). Because dispersion and visit entropy are global measures of behavior patterns that do not account for the content of the behavior, different sequences of looks would likely result in very similar overall patterns of behavior, particularly because 9-month-olds had rather higher levels of variability overall.

Changes in variability. Examining changes in the variability of infants' looking behavior (i.e., the overall patterns of behavior across a testing session void of the content of said behavior) helped us understand aspects of attention and adaptation (i.e., Hollenstein, 2013). Three-month-olds tended to have increased variability in their looking patterns (i.e., higher dispersion and visit entropy) across the testing session, whereas 9-month-olds' variability tended to decrease across trials. Because dispersion and visit entropy had values of zero on trials in which infants engaged in only one continuous look, an increase in variability across trials could be a marker of younger infants adapting to the testing environment and learning that looking at both stimuli during a single trial provided an opportunity for comparative processing of information (i.e., becoming more flexible in their behavioral patterns; Hollenstein, 2013). On the other hand, the tendency for 9-month-olds' patterns of looking to become less variable across trials could be related to fatigue. Their looking behavior, however, did not decrease dramatically or at a negatively accelerating rate, so it is unlikely that 9-month-olds as a whole became inattentive before the testing session ended. Nine-month-olds' decreases in variability could also reflect adaption to the study design, particularly because 9-month-olds showed a slight decline in variability across trials in the randomized condition, whereas 9-month-olds showed a more dramatic decrease in variability across trials in the more predictable, blocked condition. In the case of 9-month-olds in the blocked condition, the learning they experienced during previous blocks may have helped them more readily settle into a looking pattern with stronger attractor states (i.e., less variability) on subsequent trials.

The results from the 9-month-olds support our prediction that infants' behavior patterns would become more predictable or less variable across trials. We anticipated that behavior would change due to adaptation to the testing environment, and both ages appeared to exhibit linear changes in their looking patterns across trials (even though 3-month-olds showed a linear increase rather than decrease). It is possible that these changes were due to regression toward the mean and not to increased familiarity with the testing environment. For 3-month-olds in the blocked condition, however, we found evidence of nonlinear changes too. Infants' patterns of looking varied across familiar and unfamiliar race blocks, and within familiar race blocks, variability decreased across trials. These patterns suggest that even though regression toward the mean may have occurred, at least in some instances, it is likely not the only reason for changing patterns of behavior across trials. A more detailed analysis that focused on detecting nonlinear change or detecting change among subgroups of participants (such as latent class growth analysis or growth mixture modeling; e.g., Jung & Wickrama, 2008) might have better accounted for these changing dynamics.

Attractor stability. The attractor state analyses and the more traditional analyses of infants' PTLT produced similar results. Examining these analyses together helped us better understand why infants exhibited significant preferences in some instances and not others. From the traditional analyses we found that 9-month-olds did not show significant preferences for female faces (except perhaps in the randomized condition when infants, regardless of age, showed a preference for familiar race, low attractive females, but the attractor stability analyses would suggest that this preference across ages was primarily driven by 3-month-olds' strong attraction to female faces when viewing low attractive face pairs). The lack of preferences for 9-month-olds was also found in the attractor stability analyses. In general, female and male attractor states remained fairly stable across testing sessions for both conditions. Other researchers have also found a lack of preference for female faces over male faces and familiar race faces over unfamiliar race faces among 9-month-olds (e.g., Liu et al., 2015a; 2015b; Tham, Brenner, & Hay, 2015). Researchers suggest that the lack of preference among older infants could be due to their greater expertise in face processing. Because older infants have had more cumulative experience with faces than younger infants, their cognitive representations for familiar faces are likely to be more stable, so when given an opportunity to look at faces they might not typically see (i.e., males and unfamiliar races), older infants might be more able to allocate their attention to looking at novel faces (Liu et al., 2015a; 2015b). Older infants are also more proficient face processors than younger infants, so they likely processed individual faces more quickly and efficiently and then had more time to engage in comparative processing, whereas younger infants might require more time to process faces individually before engaging in comparative processing (e.g., Liu et al., 2015b; Rose et al., 2002).

Three-month-olds' behavior was also similar across dynamic systems and traditional PTLT analyses. In the blocked condition, 3-month-olds showed a significant preference for unfamiliar race, low attractive females, and they had the strongest, most stable attractor state for females when viewing low attractive face pairs. Three-month-olds also had their lowest levels of variability in looking patterns (i.e., low dispersion and visit entropy) when looking at unfamiliar race faces, and they tended to have less variable behavior when the female attractor state was stronger. These results suggest that 3-month-olds might have preferred unfamiliar race, female faces because these faces were very strong, stable attractors. Perhaps in an unfamiliar context (i.e., when looking at unfamiliar race faces that were not prototypical), younger infants gravitated toward some semblance of familiarity (i.e., females) and did not look away. In the randomized condition, female faces also appeared to be a strong, stable attractor for 3-month-olds when they were viewing low attractive face pairs. Because the race familiarity of face pairs was not predictable, when infants saw familiar race faces, they might have been more attention grabbing, which lead to infants, regardless of age, exhibiting preferences for familiar race, low attractive faces in the randomized condition. These results showed partial support for our prediction that infants in the more predictable, blocked condition would be more likely to exhibit preferences for unfamiliar race females as compared to infants in the randomized condition.

The strength of infants' female attractor states was related to individual variations in infants' overall looking patterns. Three-month-olds had their strongest attractors for females when the variability (i.e., dispersion) of their looking patterns was low, and they had the lowest levels of variability at the beginning of the testing session. On the other hand, 9-month-olds had stronger attractor states for females when the variability of their looking patterns was high, and they typically had the highest levels of variability at the beginning of the testing session. Taken together, these results suggest that 3- and 9-month-olds might have had a temporary attraction toward familiar stimuli (i.e., females) when their environmental context was new.

Interestingly, the strength of infants' attractor states for females and males was not necessarily reciprocal in all instances. These results suggest that having a strong attractor for one face does not necessarily equate to having a weak attractor for the other face of the pair. Additionally, the strength of the away attractor was not dependent on design characteristics in either condition as we had anticipated, but rather all infants, on average, exhibited a gradual increase in the strength of the look away attractor across the testing session. The changing patterns of the look away attractor were slight (i.e., ~.5% across trials). Infants tend to look away more when viewing very complex and very simple stimuli (e.g., Piantadosi, Kidd, & Aslin, 2014). Therefore, stronger looking away attractors across trials in this investigation could indicate that infants had less difficulty processing the faces as the study progressed. Additionally, infants tended to have stronger look away attractors when their looking patterns were more variable, which suggests that looking away may be a necessary component of processing the stimulus information. If looking away was associated with fatigue or disinterest in the faces, we would have likely found stronger look away attractors associated with a decrease in variability (i.e., indicating a sustained look away).

We anticipated that infants would experience the strongest, most stable female attractor state when viewing high attractive, familiar race face pairs. We did not find any evidence of this effect among 9-month-olds and found the opposite effect among 3-month-olds. Perhaps because low attractive faces are less typical and take longer to process (e.g., Trujillo, Jankowitsch, & Langlois, 2014), 3-month-olds had difficultly disengaging from these face types, which lead to very strong, stable attractor states for females within low attractive face pairs. The fact that no infants experienced strong, stable attractor states for female faces among high attractive and familiar race faces could be due to our initial interpretation of the relationship between significant preferences and stable attractor states. Because stable attractors are often ones in which it is difficult to escape (e.g., Hollenstein, 2013), we likely would not have found stable attractors if infants were engaged in comparative processing of both stimuli. We did, however, find some evidence of 9-month-olds experiencing strong, *fluid* attractor states for female faces, in general (i.e., female attractor states were strongest when 9-month-olds' behavioral patterns were the most variable).

Individual variability. Collectively infants' did not exhibit many significant preferences for female and male faces in either the randomized or blocked conditions. This lack of significance captured through an examination of group differences is likely due to the high degree of individual variability in both infants' looking patterns and the strength of their attractor states. In nearly all growth model analyses, significant individual variance was still present in the best fitting models, which indicated that the models were not fully accounting for all potential effects. Because aspects of study design, infant age, or individual differences associated with infants' overall patterns of looking could not adequately account for the differences across individuals, it suggests that other variables may contribute to infants' preferences (or lack of preferences) during these tasks. Some infants might be more sensitive to changes in context than others. Other physical, social, or emotional characteristics of infants could be related to variability across participants. These differences could be measureable like temperament or working memory span, or fleeting and less defined like hunger or fatigue. Individual differences in infants' social structure might also impact preferences. For example, infants with higher cumulative experience with male faces in the months prior to testing exhibited less preference (i.e., lower PTLT) for familiar race females during lab settings (Liu et al., 2015a). Additionally, a more precise measure of infant age could help explain some of individual differences, particularly among 3-month-olds. Younger infants tend to have difficulty disengaging from stimuli, but this tendency decreases rather dramatically between 3 and 5 months (e.g., Johnson, Posner, & Rothbart, 1991). Therefore, younger 3-month-olds may have very different patterns of looking than older 3-month-olds.

We predicted that infants would exhibit preferences for high attractive, familiar race females because prior research suggested that infants exhibited preferences for familiar race females over familiar race males when viewing faces that were most likely high attractive (i.e., magazine models and averaged faces; Quinn et al., 2002; 2008). We found a high degree of individual variability in both the randomized and blocked conditions that might suggest that infants' preferences for familiar race females over males may not be a robust effect and is sensitive to changes in stimulus characteristic across trials such as those encountered in this investigation. One way to potentially test this hypothesis would be to analyze data separately for the first block of the blocked condition. This analysis could help determine if infants exhibited the hypothesized preference for high attractive, familiar race females when they saw familiar race stimuli during the first block. When stimulus characteristics vary across all trials (even if in some instances one set of characteristics is blocked), perhaps the immediate history of infants' behavior from previous trials impacts their behavior on subsequent trials and, in a sense, washes out a potential preference they may otherwise possess.

Between group differences. Infant age contributed to many differences in infants' behavioral patterns and strength of their attractor states. Compared with 9-month-olds, 3-month-olds exhibited more significant differences in dispersion and visit entropy related to study design and stimulus presentation order in the blocked condition. Three- and 9-month-olds' behavior patterns were sometimes in opposition to each other. For example, in the randomized condition, 3-month-olds' proportion of looking to females decreased as the attractiveness of face pairs increased, whereas 9-month-olds' proportion of looking to females increased as the attractiveness of face pairs increased. Even when 3- and 9-month-olds had similar trajectories for behavioral change across trials, their initial values significantly varied. Because infant age appeared to relate to infants' patterns of behavior fairly consistently, it could be beneficial to examine infant performance separately for these two age groups. Without age contributing to individual differences, the other predictors from our model building process might better account for variability among individuals at different ages. For example, the overall variability analyses indicated that 3-month-olds in the blocked condition occasionally had decreased variability (i.e., lower dispersion and visit entropy) during the third trial of a race block. We did not, however, detect this same pattern in our other analyses of infants' variability and stability of attractor states. By removing 9-month-olds from the models, perhaps these changing patterns in dispersion would have more strongly related to time and 3-month-olds' changing attractor states. An examination of Figures 4, 5, 11, and 12 indicates that 9-month-olds appear to have more within-group similarities than do 3-month-olds (i.e., 9-month-olds' individual level-1 line equations appear to be more tightly clustered than 3-month-olds' individual level-1 line equations). These patterns suggest that 3-month-olds might have more within-group differences than 9-month-olds; therefore, discovering subgroups within the 3-month-old sample that have similar behavioral patterns and preferences might help us develop a richer interpretation for infant face processing among younger infants. Identifying subgroups with similar behaviors can better capture developmental change because aggregate estimates of group behavior can sometimes lead to a description for a population that does not actually fit for any individuals or groups within that population (e.g., von Eye & Bogat, 2006).

Conclusion. The addition of the dynamic systems examination of infant behavior patterns and attractor states contributed to understanding why infants might have exhibited certain preferences and not others. For example, when 3-month-olds had lower variability in their looking behavior (i.e., low dispersion) their female attractor states were stronger than when they had higher variability. These results could indicate that 3-month-olds might have a tendency to “get stuck” when viewing female faces. The female attractor state may be so strong for some young infants that they have difficulty escaping from it, particularly during the first portion of a testing session when the environmental context is also novel. These results support other research indicating that 3-month-olds made very few fixations shifts between faces (i.e., less than 5% of total shifts) when shown faces during two VPC trials (Liu et al., 2015b). The results from our investigation would suggest that young infants might not have initially shifted attention between faces (i.e., low variability), but across subsequent trials, they engaged in more variable looking patterns, which likely resulted in more comparative processing of the faces.

Chapter 3: Experiment 2

Infants' categorization of social groups is proposed to be an essential step in the formation of social group stereotypes (e.g., Ramsey et al., 2004). The initial development of social categories, however, is likely based on early experiences and preferences for familiar and unfamiliar groups (e.g., Bar-Haim, Ziv, Lamy, & Hodes, 2006). Infants tend to have a disproportionate amount of experience with females as compared to males (Rennels & Davis, 2008; Sugden et al., 2014), and therefore, may be relying on femininity (familiar) and masculinity (unfamiliar) cues to categorize male and female faces.

Researchers often test infants' social categorization by first familiarizing or habituating infants to a set of faces with similar characteristics (e.g., a set of 4 male faces that are all highly sex-stereotypical), and then testing infants with paired-comparisons of faces; one a novel exemplar from the just-learned category (e.g., a different highly sex-stereotypical male) and the other a novel exemplar from a different category that is distinct in some dimension of interest (e.g., a highly sex-stereotypical female or a sex-atypical male). Researchers measure the amount of time infants spend looking toward these competing test faces and make inferences based on the proportion of time they attend to the familiar and novel category stimuli. If infants show a significant novelty preference that differs from chance, then they likely formed a category for the familiarized faces and perceived the novel category face as not belonging to the just-learned category (Quinn, 2002). This inference hinges on the well-established finding that infants tend to prefer novelty (e.g., Hunter & Ames, 1988). Therefore, if infants show a significant preference for the just-learned, familiar category face during testing, then infants were likely not sufficiently familiarized or are still forming a cognitive representation for the familiar category faces (e.g., Cohen, 2004). If infants show no significant preference for one face over the other during testing, then the dimension on which the faces vary may not be perceptually salient to infants' face processing or they may be in a transitional phase between familiarity and novelty. Categorization studies allow researchers to test infants' cognitive abilities to discriminate and group items with similar properties (e.g., Mareschal & Quinn, 2001) and are a likely precursor to the development of social stereotypes; grouping and discriminating individuals is necessary before characteristics and attributes can be associated with these groups (e.g., Ramsey et al., 2004).

Several investigations have found discrepancies in infants' abilities to categorize by sex. Nine- and 10-month-olds can categorize males and females only when the faces are highly sex-stereotypical (Leinbach & Fagot, 1993; Younger & Fearing, 1999). When faces are more sex-atypical, infants who are almost a year old have difficulty categorizing by sex (Newell & Strauss, 2002; Newell, Strauss, & Best, 2003). These findings suggest that infants may be relying on sex-stereotypical cues such as masculinity and femininity rather than biological sex to group individuals.

Infants' categorization of faces might also be influenced by the attractiveness of faces. Infants show preferences for high attractive female faces and mathematically averaged female faces (i.e., morphed images of 32 female faces) relative to low attractive female faces (e.g., Langlois et al., 1987; Rubenstein, Kalakanis, & Langlois, 1999). Although the evidence for infants' preference for high attractive relative to low attractive male faces is mixed (see Ramsey, Langlois, & Marti, 2005 for review), 12-month-olds showed preferences for high attractive males relative to low attractive males when face pairs were low masculine (Rennels, Kayl, Langlois, Davis, & Orlewicz, 2016). Averaged faces are perceived to be attractive, and high attractive faces are perceived to be prototypical and more similar to one another than low attractive faces (e.g., Langlois & Roggman, 1990; Potter, Corneille, Ruys, & Rhodes, 2007;

Rubenstein et al., 1999). Therefore, infants might form categories more easily for high attractive female faces (and possibly high attractive, low masculine male faces) than for low attractive females and males.

Findings from sex categorization studies, however, are somewhat ambiguous. Infants might display preferences for females over males during test trials due to familiarity with females outside of the lab rather than due to familiarization and learning during the lab setting. For example, infants familiarized to male faces showed a novelty preference for females when paired with males during test trials; infants familiarized to females, however, looked equally toward male and female stimuli during test trials (Quinn et al., 2002). Infants who were habituated to male faces showed greater recovery to female faces, whereas infants who were habituated to female faces showed less recovery to male faces (i.e., infants looked longer to females following habituation to males than looked to males following habituation to females; Leinbach & Fagot, 1993). Quinn et al. (2002) indicated these discrepancies in infants' categorization of females and males were likely due to infants' spontaneous preference for females when paired with males, which might "interfere" with displaying a novel category preference for males following familiarization to females. Therefore, in our investigation we employed pretest trials in which infants saw the test face pairs prior to familiarization. This design manipulation allowed us to directly measure and control for potential individual differences in spontaneous preferences for test faces (Quinn, 1987).

In this investigation, we examined 12-month-olds' categorization of male and female faces that varied in femininity and attractiveness. Infants were familiarized to one of four face types: high attractive, high feminine females; low attractive, low feminine females; high attractive, high feminine males; or low attractive, low feminine males. Infants saw three sets of test trials in which familiar category exemplars were paired with novel category exemplars that differed in sex, femininity, and both sex and femininity.

Because infants likely have a cognitive representation of faces that is female-like and high attractive (e.g., Ramsey et al., 2005), we predicted that they would more easily categorize high attractive, high feminine faces than low attractive, low feminine faces. We expected infants would categorize high attractive, high feminine females most readily and would have the most difficulty forming a category for low attractive, low feminine males because these faces are the most dissimilar from their high attractive, female-like cognitive representation of faces (e.g., Ramsey et al., 2005). We were less certain of how well infants would categorize the other two face types because these faces possessed only one cue that was related to infants' cognitive representation of high attractive, female faces (i.e., high feminine males may be perceptually similar to females due to femininity but categorically distinct due to biological sex). Twelve-month-olds might use femininity cues to discriminate among test faces in the male face conditions (i.e., showing significant novel category preferences when test faces differ in femininity only) because 12-month-olds used masculinity cues to discriminate male test face pairs in a similar paradigm (Rennels et al., 2016). Infants around 10 months showed evidence of categorizing by biological sex when familiarized to sex-typical male and female faces (Leinbach & Fagot, 1993; Younger & Fearing, 1999). Therefore, biological sex might also serve as a salient cue for 12-month-olds in this investigation, particularly for infants who were familiarized to more prototypical (i.e., high attractive) faces.

Of particular interest for this investigation was examining the variability of infants' looking patterns during familiarization trials. We predicted that if infants were learning the category to which they had been exposed (e.g., high attractive, high feminine males), then the stability or variability of their looking patterns would change during the familiarization phases. Individual differences in these patterns might be indicative of the "quality" of learning that occurred. For example, infants who did not show any change in variability across familiarization trials might not encode the perceptual information necessary to form a category for the faces. For this reason, we predicted that infants would show a linear decline in the variability of their looking during familiarization (i.e., lower dispersion and visit entropy across trials). We also expected to find individual variability among infants' familiarization trajectories and differences based on the familiarization condition to which infants were exposed (i.e., infants should form categories for high attractive, high feminine females most readily and therefore show more rapid rates of decline in the variability of their behavior, which might be distinctly different from infants familiarized to low attractive, low feminine males).

A comparison of the strength and stability of attractors between the pretest and test trials might also provide an assessment of learning. If infants' real-world experiences influenced their performance during the task, then we would expect attractor states to be most stable for the high attractive, high feminine female condition. If infants perceived this face type as most familiar, then they might not have changing patterns of stability before and after familiarization. For less familiar face types (low attractive, low feminine male faces), however, some learning might occur during familiarization. In that case, we would expect infants who viewed less familiar faces to have more variability/less stability in pretest looking patterns as compared to infants who saw more familiar faces types. After familiarization, however, infants who saw less familiar face types might have more stable looking patterns that were more similar to infants who saw familiar face types.

Finally, about 20% of our infant sample had primary caregivers who were not Caucasian, but all infants saw Caucasian faces during the study. Therefore, we included the primary caregiver's race as a variable to help account for potential differences in performance based on infants' real-world experiences with different races and ethnicities (i.e., roughly 88% of infants' social interactions are with faces from the same race as the primary caregiver; Rennels & Davis, 2008; Sugden et al., 2014). Because of an even greater lack of familiarity from which to build category knowledge, we anticipated that the above predictions would be even more pronounced for the subgroup of infants who did not have Caucasian primary caregivers.

Method

Participants. Infants aged 12 months (N = 83, 43 girls; M_{days} = 365.52, SD_{days} = 9.54) participated. All infants had female primary caregivers. Parents reported infants' race as White (64), Black/African American (2), Asian (3), some other race or multiple races (10), or did not report race (4), and reported infants' ethnicity as Spanish/Hispanic/Latino (4), Mexican/Mexican American/Chicano (14), Cuban (1), Puerto Rican (1), not Spanish/Hispanic/Latino (58), or did not report ethnicity (5). We divided infants from these racial/ethnic backgrounds into two groups: infants with non-Caucasian primary caregivers (22) and infants with Caucasian primary caregivers (61). We recruited participants in a similar manner as Experiment 1. Data from an additional 56 infants were not included in analyses for the following a priori reasons: fussiness (36), preterm (born more than 25 days prior to the due date with a birth weight less than 2.49 kg; 9), parent interaction (6), and experimenter error (5). Families received a bib or t-shirt for participating.

Stimulus Faces. Stimulus faces consisted of 22 male and 24 female college-aged volunteers who self identified as non-Hispanic/White. All faces were standardized in a manner similar to those in Experiment 1. At least 40 judges rated faces for attractiveness and femininity using a 5-point scale ranging from 1 (*not very attractive/feminine*) to 5 (*very attractive/feminine*). We grouped faces into low attractive, low feminine (M_{att} = 1.49, *SD* = 0.24; M_{fem} = 1.83, *SD* = 0.24), high attractive, high feminine (M_{att} = 3.38, *SD* = 0.28; M_{fem} = 3.47, *SD* = 0.65), low attractive, high feminine (M_{att} = 1.53, *SD* = 0.26; M_{fem} = 3.56, *SD* = 0.26), and high attractive, low feminine (M_{att} = 3.45, *SD* = 0.19; M_{fem} = 2.58, *SD* = 0.96) categories. High attractive faces differed from low attractive faces, $t(40) = 26.06$, $p < .001$, and high feminine faces differed from low feminine faces, $t(41) = 9.38$, $p < .001$. Male and female faces did not differ in attractiveness ratings, $t(44) = 0.57$, $p = .57$, but females had slightly higher femininity ratings than males, $t(44) = 2.04$, $p = .05$. We created four conditions of faces (high attractive, high feminine female; high attractive, high feminine male; low attractive, low feminine female; and low attractive low feminine male). Each condition consisted of four familiarization faces, three familiar category faces, and three novel category faces. The novel category faces differed from the familiar category faces in sex only, femininity only, and both sex and femininity. For example, the high attractive, high feminine female condition consisted of seven high attractive, high feminine females (four for the familiarization phase and three for the test phase), one high attractive, high feminine male, one high attractive, low feminine female, and one high attractive, low feminine male (the latter three were the novel category test faces). We created two sets of stimuli (sets A and B). We had difficulty acquiring two unique sets of faces because test face pairs had to match in attractiveness but differ in sex and/or femininity, and familiarization and test faces from the same condition had to match in both attractiveness and femininity. Whenever possible, faces that were test stimuli in set A were familiarization stimuli in set B. We also included ten faces in set

B that were not included in set A. See Appendix B: Table 22 for a complete list of the stimulus faces for sets A and B for all four conditions.

Apparatus. The study setup was identical to that of Experiment 1.

Procedure. Infants were randomly assigned to one of four familiarization conditions: high attractive, high feminine females (HHF); high attractive, high feminine males (HHM); low attractive, low feminine females (LLF); or low attractive, low feminine males (LLM) and saw stimuli from either set A or B. Infants participated in three phases: pretest, familiarization, and test phases. During the pretest phase, infants saw six trials identical to the test phase so as to examine a priori preferences for the test stimuli (Quinn, 1987). During the familiarization phase, infants saw 12 trials in which four faces from the assigned condition were presented in three randomized blocks with the constraint that no face repeated on sequential trials. For each trial, the same face appeared on both monitors. For the test phase, infants saw three sets of novel face pairs that consisted of a novel exemplar from the familiarized category paired with a novel category exemplar that differed in sex, femininity, or both sex and femininity. Test face pairs were presented twice in randomized blocks with left-right reversal on the second showing. All 24 trials were 15 s long.

Data coding and variables. Data were coded in the same manner as Experiment 1. We calculated interrater agreement for looking time (M_{ICC} = .988, range .832 - .999) for each infant's data. We then chose the most reliable coder for all analyses and rounded looking time data to 100 ms increments for both traditional PTLT and dynamic systems analyses. For pretest and test trials, we computed PTLT toward the novel category face for each block of trials (i.e., we combined data within each left-right reversal block and then divided total time looking toward the novel category face by total looking time toward both faces) and obtained dispersion, visit entropy, and attractor stability variables (i.e., proportion of time looking toward novel category, familiar category, and away) for each trial. For the familiarization trials we computed dispersion and visit entropy for each trial and the attractor state of proportion of looking toward stimuli for each trial.

Data Analyses

Traditional infant looking time analyses. First, we determined whether infants showed any a priori preferences for the test faces by conducting a 2 x 2 x 3 (Familiarization Condition Sex [female, male] x Familiarization Condition Attractiveness [low, high] x Test Comparison [change in sex, change in femininity, change in sex and femininity] SAS proc mixed analysis with repeated measures and pretest PTLT as the dependent measure. We compared this base model to models that included test comparison order (i.e., comparison occurred during the first, second, or third test block), infant sex, and primary caregiver race (i.e., not Caucasian or Caucasian) to determine the model that provided the best fit to the data and included all significant effects and interactions. The best fitting model for the pretest PTLT was the base model. For all significant effects and interactions we compared least-squares means using Tukey-Kramer adjustments. Finally, we followed up significant group differences by comparing least-squares means to chance (50%) and corrected for multiple *t*-tests using the Benjamini and Hochberg (2000) adaptive false discovery rate.

Next, we determined if infants had been sufficiently familiarized to the familiarization categories by comparing the average of their looking time across the first block of familiarization trials (i.e., average looking time across familiarization trials 1 through 4) with the average of their looking time across the last block of familiarization trials. We conducted a 2 x 2 x 2 (Familiarization Condition Sex [female, male] x Familiarization Condition Attractiveness [low, high] x Familiarization Block [first, last]) SAS proc mixed analysis with repeated measures and average looking time as the dependent measure. We used the same procedure as we did with the analysis of the pretest PTLT and compared the base model to models that included infant sex and primary caregiver race. The base model provided the best fit to the data.

Finally, to determine if infants exhibited significant preferences for the test stimuli following familiarization, we conducted a 2 x 2 x 3 (Familiarization Condition Sex [female, male] x Familiarization Condition Attractiveness [low, high] x Test Comparison [change in sex, change in femininity, change in sex and femininity]) SAS proc mixed analyses with repeated measures and included pretest PTLT as a random variable to control for initial preferences for stimulus faces. As with the pretest analysis, we compared models with test comparison order, infant sex, and primary caregiver race. For test PTLT, the best fitting model that included all significant effects was the 2 x 2 x 3 x 3 (Familiarization Condition Sex x Familiarization Condition Attractiveness x Test Comparison x Test Comparison Order).

Dynamic systems perspective analyses.

Overall variability. We examined potential group differences in variability by conducting separate SAS proc mixed analyses for dispersion and visit entropy using the same analyses and model comparisons as those used for the traditional looking time analyses. First, we examined infants' initial dispersion and visit entropy during the pretest trials and determined the best fitting model for dispersion was the base model with the addition of infant sex (i.e., Familiarization Condition Sex x Familiarization Condition Attractiveness x Test Comparison x Infant Sex), whereas the base model fit best for visit entropy. For the familiarization analysis, we calculated average dispersion and visit entropy for the first and last blocks of the familiarization phase and determined that the base model with the addition of infant sex (i.e., Familiarization Condition

Sex x Familiarization Condition Attractiveness x Familiarization Block x Infant Sex) fit best for dispersion, and the base model fit best for visit entropy. Finally, for the test phase, we determined that for both dispersion and visit entropy the 2 x 2 x 3 x 3 (Familiarization Condition Sex x Familiarization Condition Attractiveness x Test Comparison x Test Comparison Order) model provided the best fit while including all significant effects and interactions.

Changes in variability. To determine whether infants' behavior varied as a function of time, we examined changes in dispersion and visit entropy using growth curve analyses. Because the study consisted of three phases we conducted separate analyses for the pretest, familiarization, and test phases. First we calculated intraclass correlation coefficients (ICC) without predictors to determine that there was sufficient variation among infants' dispersion, $ICC_{pretest} = .12$, $ICC_{fam} = .12$, $ICC_{test} = .24$, and visit entropy scores, $ICC_{pretest} = .20$, $ICC_{fam} = .11$, $ICC_{test} = .18$. We then proceeded with a similar model building process as Experiment 1. First we compared models with linear, quadratic, and cubic terms and chose the best fitting model. Then for the pretest and test phases, we added the level-1, time-varying predictors of test comparison and Text Comparison x Time and compared model fit between random and fixed effects (the familiarization phase did not have any level-1 predictors). Finally, for level-2 predictors we included infant sex, familiarization condition sex (female or male faces), familiarization condition attractiveness (low or high), and primary caregiver race (not Caucasian or Caucasian). We added the level-2 predictors to the best fitting model from the previous steps and again compared model fit for random and fixed effects. Because all predictors were categorical, all variables were dummy coded. For test comparison, 0, 1, and 2 reflected comparisons that differed in sex, femininity, and both sex and femininity, respectively. For infant sex, familiarization condition sex, familiarization condition attractiveness, and primary caregiver

(PC) race, zero values reflected female infants, female faces, low attractive faces, and non-Caucasian PCs, respectively.

Attractor Stability. To determine whether infants exhibited stable attractor states across pretest and test trials and if these states changed as a function of time or stimulus characteristics, we conducted growth models for the proportion of looking toward novel stimuli, familiar stimuli, and away. We employed the same model building process as that used for assessing changes in variability. The ICCs for novel proportion, $ICC_{pretest} = .12$, $ICC_{test} = .08$, familiar proportion, $ICC_{pretest} = .16$, $ICC_{test} = .17$, and away proportion, $ICC_{pretest} = .37$, $ICC_{test} = .34$, indicated that sufficient variance among individuals likely existed to warrant HLM analysis. For the attractor stability analyses, we included dispersion, Dispersion x Time, visit entropy, and Visit Entropy x Time as additional level-1 predictors. For pretest and test phases, we chose the best fitting, most parsimonious model for each attractor state.

For the familiarization phase, the same face appeared on both left and right monitors, so we used the proportion of total looking time (looking time divided by trial length) to assess the stability of looking across familiarization trials and conditions. We used the same model building process that we used for the familiarization phase in the changes in variability analyses with the addition of dispersion, visit entropy, and their respective interactions with time as potential level-1 predictors. The ICC for the model without predictors was .29 indicating that there was variability among infants in their proportion of looking during familiarization.

Results

Traditional infant looking time analyses. Results for the pretest phase revealed a significant main effect for familiarization condition sex, $F(1,79) = 4.15$, $p = .05$, $\omega^2 = .009$, and a main effect for familiarization condition attractiveness, $F(1,79) = 4.15$, $p = .05$, $\omega^2 = .011$, which were superseded by a Familiarization Condition Sex x Familiarization Condition Attractiveness interaction, $F(1,79) = 8.83$, $p = .004$, $\omega^2 = .030$. A comparison of least-squares means revealed that infants who saw pretest trials as part of the high attractive, high feminine male condition had a significantly higher pretest PTLT (*LSM* = .55, *SE* = .01), in general, than infants in the low attractive, low feminine female (*LSM* = .50, *SE* = .01), low attractive, low feminine male (*LSM* = .49, *SE* = .01), or high attractive, high feminine female (*LSM* = .49, *SE* = .01) conditions, *p*s < .03. Pretest PTLT to chance (50%) comparison revealed that only the infants from the high attractive, high feminine male condition had a pretest PTLT that significantly differed from chance, $t(79) = 3.81$, $p = .001$. These results indicated that the infants who would eventually be familiarized to high attractive, high feminine males had an initial preference for the "novel" or competing category stimuli. Regardless of the face with which high attractive, high feminine males were paired (i.e., a high attractive, high feminine female; a high attractive, low feminine male; or a high attractive, low feminine female), infants collectively and spontaneously looked longer toward the latter three faces.

For the familiarization analyses, infants showed a significant decrease in looking between the first block (*LSM* = 9.15 s, *SE* = 0.26 s) and last block (*LSM* = 7.96 s, *SE* = 0.26 s) of the familiarization phase, $F(1,79) = 26.11$, $p < .001$, $\omega^2 = .053$. Only the main effect for familiarization block was significant, which suggested that infants significantly decreased their looking across trials regardless of the condition to which they were familiarized.

Results for the test PTLT analysis revealed a significant main effect for test comparison, $F(2,212) = 7.84$, $p < .001$, $\omega^2 = .036$, and a significant main effect for test comparison order, $F(2,212) = 4.98$, $p = .008$, $\omega^2 = .016$. A comparison of least-squares means for test comparison revealed that infants had a significantly lower PTLT toward novel stimuli when test face pairs differed in femininity than when test face pairs differed in sex or differed in both sex and femininity, *p*s < .05. Additionally, comparing novel PTLT to chance (50%) looking revealed that infants showed preferences significantly greater than chance when test comparisons differed in sex, $t(212) = 3.77$ $p < .001$, and differed in both sex and femininity, $t(212) = 2.17$, $p = .05$. Thus, regardless of familiarization condition, 12-month-olds treated test faces that differed in sex as a novel category, but showed no categorical distinction when the test faces differed in femininity only. For the test comparison order effect, an examination of least-squares means revealed that infants looked significantly more toward the novel category face during the third test block than during the second test block, $p < .001$. Finally, PTLT to chance comparison revealed that infants' looking toward novel category faces was significantly greater than chance during the third test block, $t(212) = 3.78$ $p < .001$. Twelve-month-olds, therefore, treated test faces that differed in sex, femininity, or both cues as a novel category when the comparison occurred during the third test block. See Table 12 for least-squares means and standard errors for novel category PTLT based on test comparison and test comparison order. See Appendix C: Table 23 for a summary of all significant results from Experiment 2.

Table 12
Least-squares Means and Standard Error for Percentage of Total Looking Time (PTLT) Toward Novel Category Test Faces Divided by Test Comparison and Test Comparison Order

	LS mean	(SE)
Test comparison		
differed in sex	.56***	(.02)
differed in femininity	.48	(.02)
differed in sex & femininity	.54*	(.02)
Test comparison order		
first trial	.52	(.02)
second trial	.50	(.02)
third trial	.56***	(.02)

* $p < .05$, ** $p < .01$, *** $p < .001$, significantly differs from chance (50%)

Dynamic systems perspective analyses.

Overall variability. For dispersion during the pretest phase, results indicated only a significant main effect for infant sex, $F(1,75) = 4.89$, $p = .03$, $\omega^2 = .014$. During pretest trials, female infants had lower dispersion (i.e., fewer looks and/or longer looks, $LSM = .77$, $SE = .01$) than male infants ($LSM = .81$, $SE = .01$). We found no significant effects for visit entropy during the pretest phase.

We found the same pattern of results during the familiarization phase. Overall, male infants had more dispersed looking patterns (i.e., shorter and/or more frequent looks, $LSM = .77$, $SE = .01$) than female infants ($LSM = .74$, $SE = .01$, $F(1,75) = 4.03$, $p = .05$, $\omega^2 = .024$). Again, we found no significant effects for visit entropy.

For dispersion during the test phase, there was a significant main effect for test comparison order, $F(2,461) = 3.03$, $p = .05$, $\omega^2 = .004$, that was superseded by a significant Familiarization Condition Sex x Test Comparison x Test Comparison Order interaction, $F(4,461) = 2.73$, $p = .03$, $\omega^2 = .016$. Comparison of least-squares means for the interaction, however, revealed no significant differences among means. A comparison of least-squares means for the main effect indicated that infants had significantly higher dispersion during the first test block ($LSM = .73$, $SE = .02$) than during the second test block ($LSM = .68$, $SE = .02$, $p < .05$). Infants' dispersion during the third test block ($LSM = .72$, $SE = .02$) did not significantly differ from the first or second blocks, *p*s > .05. These results indicated that infants exhibited a decrease in the variability of their looking patterns across the test block. Regardless of what test comparison infants saw, they had longer and/or fewer looks during the second test block than they had during the first.

Visit entropy during the test phase had the same pattern of results as dispersion. The significant main effect for test comparison order, $F(2,461) = 4.05$, $p = .02$, $\omega^2 = .006$, was superseded by a significant Familiarization Condition Sex x Test Comparison x Test Comparison Order interaction, $F(4,461) = 4.47$, $p = .002$, $\omega^2 = .030$, which resulted in no significant effects. Comparison of least-squares means for the main effect indicated that infants had significantly higher visit entropy during the first test block (*LSM* = 1.38, *SE* = 0.10) than during the second test block (*LSM* = 1.29, *SE* = 0.10, $p < .05$), but the third test block (*LSM* = 1.35, *SE* = 0.10) did not significantly differ from the first or second blocks, *p*s > .05. These results indicated that infants also had more predictable looking patterns (i.e., fewer looks, less chaotic looking patterns, and/or more predictable sequences of looks) during the second test block than the first block.

Changes in variability. For the pretest phase, dispersion and visit entropy did not vary as a function of time. For dispersion, the best fitting model included only infant sex. Female infants had an average pretest dispersion of .77 (*SE* = .01), and male infants' average dispersion was .81 (*SE* =.01). Although including infant sex accounted for 13.66% of variance above the empty model, there was still significant variance to be explained. For visit entropy, there were no significant predictors. These results indicated the same pattern as the overall variability results—male infants had more variable looking patterns (i.e., more dispersed looks that were shorter and/or more frequent) than female infants.

For the familiarization phase, dispersion varied as a function of time but visit entropy did not. The best fitting model for dispersion included both a linear and quadratic term, and no other predictors provided a significant contribution to the model (see Table 13). Although infants significantly differed in their initial dispersion scores, they had a slightly negative instantaneous rate of change and accelerating quadratic function that were constant across individuals (i.e., variance for the linear and quadratic terms were not significant and were, therefore, fixed; see Figure 14). The resulting model involved a slight U-shaped bend in infants' dispersion during the middle trials of the familiarization phase, which indicated that during the middle of familiarization, infants' looking patterns were temporarily more stable (i.e., longer and/or fewer looks) than at the beginning and end of familiarization. For visit entropy, including infant sex provided the best fitting model. Female infants had an average visit entropy of 1.55 (*SE* = .02), and male infants had an average visit entropy of 1.60 (*SE* = .02), $t(81) = 2.01$, $p = .05$. These results indicated that male infants had less predictable looking patterns (i.e., more frequent looks and/or more transitions between and away from the stimuli) during familiarization than female infants.

Table 13

Growth Model Comparison for Dispersion for the Familiarization Phase

	Unconditional Model			Conditional Model		
Fixed Effects	*Coef. (SE)*	*t (df)*	*p*	*Coef. (SE)*	*t (df)*	*p*
Intercept (β_{00})	.751 (.012)	69.92 (82)	<.001	.774 (.012)	62.24 (82)	<.001
Time (linear; β_{10})	-.001 (.001)	-0.77 (82)	.443	-.014 (.005)	-3.06 (911)	.002
Time (quadratic; β_{20})				.001 (.0004)	2.94 (911)	.003
Random Effects *(Var. Components)*	*Variance*	*χ^2 (df)*	*p*	*Variance*	*χ^2 (df)*	*p*
Intercept (r_{0i})	.004	144.75 (82)	<.001	.003	216.61 (86)	<.001
Time (r_{1i})	.00003	101.51 (82)	.071			
Level-1 (e_{ti})	.019			.019		
				Variance Explained		
				Intercept	38.14%	
				Time	0%	
				Level-1	0%	

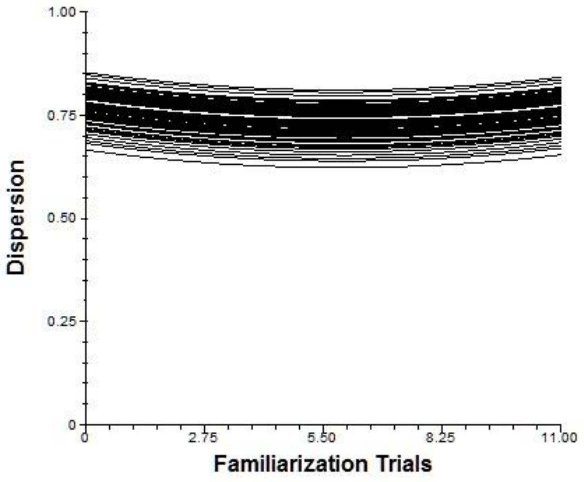

Figure 14. Individual level-1 line equations for dispersion during the familiarization phase.

For the test phase, dispersion and visit entropy had models in which the linear term and the level-1 predictor of test comparison contributed to the best fitting model (see Table 14). Although time and test comparison did not significantly contribute to either dispersion or visit entropy, including these terms provided the best fitting models. Infants' variability decreased slightly (lower dispersion & visit entropy) across trials. Infants' variability also differed based on test comparison. Infants had the lowest variability when test faces differed in sex, then variability increased when test faces differed in femininity, and differed in both sex and femininity, respectively. Both of these effects indicated that time and stimulus characteristics affected the manner in which infants looked during the test trials. Infants had slightly more stable looking patterns (i.e., longer looks, fewer looks, and/or fewer transitions between and away from stimuli) toward the end of the study and when viewing test faces that differed in sex only.

Table 14

Best Fitting Growth Models for Dispersion and Visit Entropy for the Test Phase

	Dispersion Conditional Model			Visit Entropy Conditional Model		
Fixed Effects	*Coef. (SE)*	*t (df)*	*p*	*Coef. (SE)*	*t (df)*	*p*
Intercept (β_{00})	.709 (.019)	37.97 (82)	<.001	1.494 (.035)	42.14 (82)	<.001
Time (β_{10})	-.007 (.005)	-1.46 (82)	.149	-0.004 (.010)	-0.41 (82)	.681
Test Comparison (β_{20})	.019 (.010)	1.86 (82)	.066	0.020 (.019)	1.07 (82)	.288
Random Effects *(Var. Components)*	*Variance*	χ^2 *(df)*	*p*	*Variance*	χ^2 *(df)*	*p*
Intercept (r_{0i})	.007	98.56 (82)	.103	0.039	128.13 (82)	.001
Time (r_{1i})	.0004	92.99 (82)	.191	0.003	107.68 (82)	.030
Test Comparison (r_{2i})	.001	86.03 (82)	.359	0.005	83.81 (82)	.424
Level-1 (e_{ti})	.029			0.084		
	Variance Explained			*Variance Explained*		
Intercept	0%			0%		
Time	0%			20.31%		
Level-1	3.73%			2.26%		

Attractor Stability. For the pretest phase the best fitting model for novel proportion (i.e., the faces that would be the novel category exemplars during the test trials) was one in which dispersion was included as a level-1 predictor, even though dispersion did not significantly contribute to the model. For both familiar proportion (i.e., the faces that would be the familiar category exemplars during the test phase) and away proportion, the best fitting models included familiarization condition attractiveness as a significant level-2 predictor. When infants had more varied looking patterns (i.e., shorter, less frequent looks, and/or more transitions) they also tended to have higher proportions of looking to the to-be-novel stimuli. Because the novel and familiar categories for the pretest phase were not yet novel or familiar to our infant participants, it is difficult to interpret the results in terms of their categorical attractor states. We can, however, infer what these results meant for infants' initial looking patterns in a more general sense. The results for the to-be-familiar attractor state and the away attractor states are reciprocal, therefore, these results suggested that infants who saw low attractive faces had higher proportions of looking toward the stimuli (i.e., less looking away) than infants who saw high attractive faces (See Tables 15 and 16 for the best fitting models for each attractor state). The results for the pretest attractor state analysis suggested that, in general, the more actively engaged infants were (i.e., more variable their behavior) the more they looked toward the stimuli, and infants who saw low attractive face pairs might have initially been more attentive to the faces than infants who saw high attractive face pairs.

Table 15

Best Fitting Model for the Attractor State of Novel Proportion for the Pretest Phase

	Novel Proportion		
Fixed Effects	*Coef. (SE)*	*t (df)*	*p*
Intercept (β_{00})	.218 (.065)	3.36 (82)	.001
Dispersion (β_{10})	.145 (.076)	1.90 (82)	.060
Random Effects			
(Var. Components)	*Variance*	χ^2 *(df)*	*p*
Intercept (r_{0i})	.118	131.70 (82)	<.001
Dispersion (r_{1i})	.134	112.43 (82)	.014
Level-1 (e_{ti})	.019		
	Variance Explained		
Intercept	0%		
Level-1	11.73%		

Table 16

Best Fitting Models for the Attractor States of Familiar Proportion and Away Proportion for the Pretest Phase

	Familiar Proportion			Away Proportion		
Fixed Effects	*Coef. (SE)*	*t (df)*	*p*	*Coef. (SE)*	*t (df)*	*P*
Intercept (β_{00})	.349 (.013)	26.83 (81)	<.001	.313 (.021)	14.93 (81)	<.001
Fam. Cond. Attractiveness (β_{20})	-.046 (.019)	-2.43 (81)	.017	.063 (.031)	2.05 (81)	.044
Random Effects						
(Var. Components)	*Variance*	χ^2 *(df)*	*p*	*Variance*	χ^2 *(df)*	*P*
Intercept (r_{0i})	.004	162.71 (81)	<.001	.015	358.02 (81)	<.001
Level-1 (e_{ti})	.023			.027		
	Variance Explained			*Variance Explained*		
Intercept	12.68%			6.18%		
Level-1	0%			0%		

For the familiarization phase, the best fitting model included only significant linear and quadratic terms (see Table 17 and Figure 15). In general, infants initially had a linear decrease in the proportion of time they looked during familiarization, across trials, however, their proportion of looking tended to increase again (i.e., slight U-shaped bend) so that by the end of the familiarization phase infants, on average, were looking toward the stimuli only about 4% less than they were on Trial 1. These results were similar to infants' variability of behavior (i.e., dispersion) during familiarization. Unlike dispersion, however, infants had significant individual variability among their trajectories of looking toward stimuli across the familiarization trials, which indicated that individual infants had trajectories that deviated from this general pattern.

Table 17

Growth Model Comparison for Proportion of Looking for the Familiarization Phase

	Unconditional Model			Conditional Model		
Fixed Effects	*Coef. (SE)*	*t (df)*	*p*	*Coef. (SE)*	*t (df)*	*P*
Intercept (β_{00})	.594 (.017)	34.01 (82)	<.001	.641 (.019)	34.39 (82)	<.001
Time (linear; β_{10})	-.009 (.002)	-4.90 (82)	<.001	-.037 (.007)	-5.04 (82)	<.001
Time (quadratic; β_{20})				.003 (.0007)	3.85 (82)	<.001
Random Effects *(Var. Components)*	*Variance*	χ^2 *(df)*	*p*	*Variance*	χ^2 *(df)*	*p*
Intercept (r_{0i})	.015	198.36 (82)	<.001	.011	131.23 (82)	<.001
Time (linear, r_{1i})	.00001	86.64 (82)	.342	.001	114.80 (82)	.010
Time (quadratic, r_{2i})				.00001	123.97 (82)	.002
Level-1 (e_{ti})	.036			.033		
				Variance Explained		
				Intercept	27.92%	
				Time (linear)	0%	
				Level-1	7.07%	

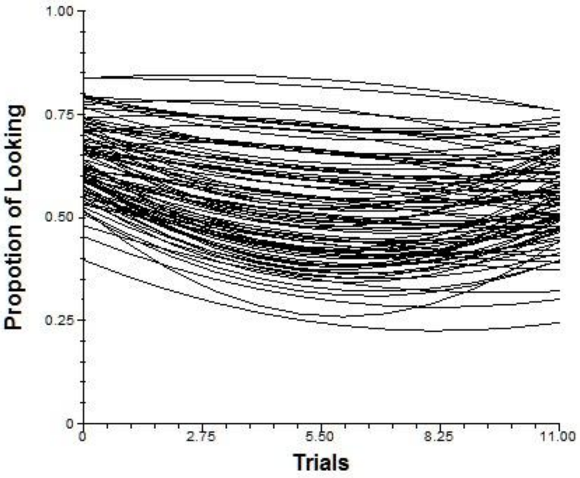

Figure 15. Individual level-1 line equations for proportion of looking during the familiarization phase.

For the test phase, the best fitting model for the novel attractor (i.e., novel proportion) included a linear component and visit entropy as a level-1 predictor. Primary caregiver race also significantly contributed to the linear term (see Table 18 and Figure 16). As infants engaged in more frequent looks and transitions (i.e. higher visit entropy), their looking toward the novel stimuli also increased. Infants with non-Caucasian PCs exhibited a significant decrease in their looking toward the novel category faces across consecutive test trials, whereas infants with Caucasian PCs exhibited a slight (.003) increase in their looking toward novel faces across test trials.

Table 18

Model Comparison for the Attractor State of Novel Proportion for the Test Phase

	Unconditional Model			Conditional Model		
Fixed Effects	*Coef. (SE)*	*t (df)*	*p*	*Coef. (SE)*	*t (df)*	*p*
Intercept (β_{00})	.308 (.017)	18.10 (82)	<.001	.193 (.066)	2.93 (82)	.004
Time (β_{10})	-.002 (.005)	-0.29 (82)	.770	-.012 (.008)	-1.56 (81)	.122
by PC race (β_{11})				.015 (.007)	2.05 (81)	.044
Visit Entropy (β_{20})				.078 (.039)	2.00 (82)	.049
Random Effects (Var. Components)	*Variance*	χ^2 *(df)*	*p*	*Variance*	χ^2 *(df)*	*p*
Intercept (r_{0i})	.003	96.78 (82)	.127	.120	162.61 (82)	<.001
Time (r_{1i})	.0001	90.09 (82)	.253	.0002	105.47 (81)	.035
Visit Entropy (r_{2i})				.035	159.78 (82)	<.001
Level-1 (e_{ti})	.039			0.035		
				Variance Explained		
				Intercept	0%	
				Time	0%	
				Level-1	10.61%	

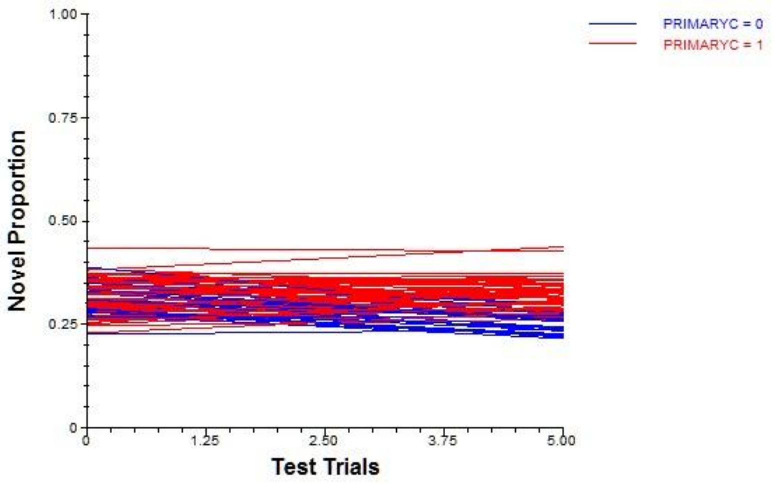

Figure 16. Individual level-1 line equations for novel proportion for infants during the test phase. Other predictors in the model (i.e., visit entropy) were held constant at the mean. PRIMARYC of 0 indicated infants with primary caregivers who were not Caucasian, and PRIMARYC of 1 were infants with Caucasian primary caregivers.

For familiar proportion, a model including test comparison and dispersion provided the best fit to the data (see Table 19). As infants’ variability in looking increased (i.e., higher dispersion), so did their proportion of looking toward the familiar category. Infants had the most stable familiar category attractor state (i.e., highest proportion of looking toward familiar category faces) when test comparisons differed in both sex and femininity. The stability of infants' familiar category attractor state decreased for comparisons that differed in femininity only and sex only, respectively.

For the look away attractor state (i.e., away proportion), the best fitting model included only linear and quadratic terms. Although infants varied in their initial proportion of away looking, their instantaneous rate of change and decelerating change did not significantly vary across individuals (see Table 20 and Figure 17). The proportion of time infants looked away during the test trials had a slight inverted U-shape indicating a momentary increase in the proportion of looking away during the middle test trials. These results indicate that infants were attentive to the test trials (i.e., there were no dramatic increases in looking away), and all infants had a similar inverted U-shaped trajectory of their proportion of time spent looking away.

Table 19

Best Fitting Models for Familiar Proportion for the Test Phase

	Familiar Proportion		
Fixed Effects	*Coef. (SE)*	*t (df)*	*p*
Intercept (β_{00})	.068 (.051)	1.33 (82)	.186
Test Comparison (β_{10})	.020 (.009)	2.18 (331)	.030
Dispersion (β_{20})	.269 (.063)	4.27 (82)	<.001
Random Effects (Var. Components)	*Variance*	χ^2 *(df)*	*p*
Intercept (r_{0i})	.081	203.70 (82)	<.001
Dispersion (r_{2i})	.099	137.41 (82)	<.001
Level-1 (e_{ti})	.028		
	Variance Explained		
Intercept	0%		
Level-1	14.73%		

Table 20

Model Comparison for Away Proportion for the Test Phase

	Unconditional Model			Conditional Model		
Fixed Effects	*Coef. (SE)*	*t (df)*	*p*	*Coef. (SE)*	*t (df)*	*p*
Intercept (β_{00})	.394 (.026)	15.34 (82)	<.001	.364 (.028)	13.15 (82)	<.001
Time (linear, β_{10})	.009 (.006)	1.32 (82)	.189	.053 (.020)	2.58 (413)	.010
Time (quadratic, β_{20})				-.009 (.004)	-2.25 (413)	.025
Random Effects						
(Var. Components)	*Variance*	χ^2 *(df)*	*P*	*Variance*	χ^2 *(df)*	*p*
Intercept (r_{0i})	.031	193.86 (82)	<.001	.025	343.99 (82)	<.001
Time (linear, r_{1i})	.0009	113.64 (82)	.012			
Level-1 (e_{ti})	.045			.047		
				Variance Explained		
				Intercept	0%	
				Level-1	20.52%	

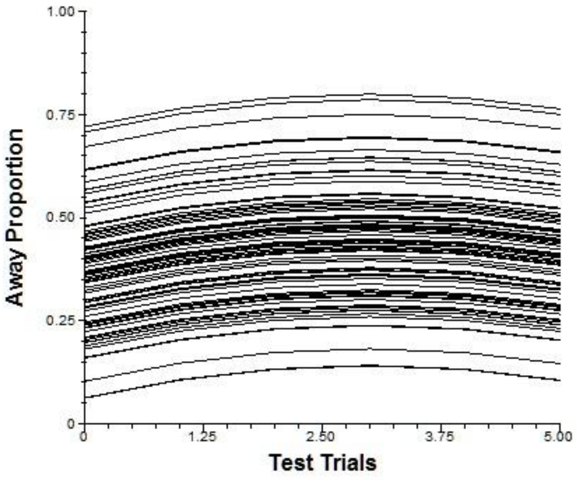

Figure 17. Individual level-1 line equations for away proportion during the test phase.

Discussion

In Experiment 2 we found evidence that infants in all four familiarization conditions categorized faces using biological sex. From the attractor state analyses, however, we found that this ability might have been moderated by infants' real-world experiences with Caucasian faces. The attractor state analysis in conjunction with measures of variability indicated that infants might have experienced different types of preferences during the test trials (some more stable than others). In general, infants exhibited fairly stable looking patterns across each phase of the study, and variability of behavior did not differ across familiarization conditions.

Infants exhibited significant novel category preferences when test faces differed in sex or both sex and femininity. These results occurred regardless of the familiarization condition to which infants were exposed. As with Experiment 1, infants exhibited few significant group preferences associated with characteristics of the study design. We anticipated that infants would have the most difficulty forming a category for faces in the low attractive, low feminine male condition, and would most likely be sensitive to changes in femininity following familiarization to the two male face categories. We did not find evidence to support either prediction. Infants appeared to form categories for all four familiarization conditions and used biological sex or a combination of biological sex and femininity to discriminate among test faces. Additionally, infants showed a significant novelty preference for the last block of test faces regardless of familiarization condition or test face comparison. Because we did not find results based on familiarization condition, as anticipated, it could suggest that 12-month-olds' cumulative experience with faces in the real-world had enabled them to process both the typical (i.e., high attractive) and atypical (i.e., low attractive) stimuli in an equivalent manner. Alternatively, infants who viewed less typical face categories may have exhibited null preferences during testing that did not significantly vary from infants in other conditions who did exhibit significant preferences (i.e., a novelty preference of .53 might not significantly differ from chance, but might also not significantly differ from a novelty preference of .56). In the latter case, we would be more likely to find an aggregate, group preference that differed from chance. Interestingly, no infants appeared to group faces based on femininity cues alone. Perhaps because of the competition from test face comparisons that differed in biological sex, these more subtle distinctions in facial cues were not as apparent to our infant participants. Examining the data separately by condition and/or test comparison could help us determine if infants who viewed less typical face types exhibited null preferences.

During the pretest phase, infants in the high attractive, high feminine male condition showed significant preferences for faces that were not high attractive, high feminine males (i.e., they showed a collective preference for high attractive, high feminine females; high attractive, low feminine males; and high attractive, low feminine females). Across these pretest trials, infants saw four male faces and two female faces. This slight imbalance might have resulted in infants showing a familiarity preference for female faces when such faces were available. Interestingly, the infants in the high attractive, high feminine female condition did not also show spontaneous preferences for female faces, even though the face comparisons were very similar to the high attractive, high feminine male condition. Infants in the high attractive, high feminine female condition, however, saw four female faces and two male faces. The preference for (mostly) females in the former instance but not the latter could be the result of this slight discrepancy between the total number of females and males infants saw (i.e., real-time dynamics and on-line learning may have contributed to these preferences). We could examine the pretest data separately by familiarization condition and comparison type to determine if these potential difference affected infants' initial preferences. To help understand why these effects occurred, we looked more closely at infants' behavioral patterns and changing attractor states across each phase of this investigation.

Overall variability. Infants' overall variability did not appear to be related to the stimulus comparisons in the pretest or test phases, nor to the condition to which infants were familiarized. Infants did, however, experience higher levels of variability (i.e., dispersion and visit entropy) during the first block of the test phase as compared to the second block. These results could be indicative of a momentary reorganization of infant behavior due to the change in context from the familiarization phase to the testing phase.

Changes in variability. Infants' patterns of looking did not change much across pretest or test phases. For both the overall variability and changes in variability analyses, some sex differences among infants emerged in which males had more variability in their behavioral patterns (i.e., higher dispersion and visit entropy) than females. These sex differences occurred during the pretest and familiarization phases, but not during the test phase, so it is unclear at this time if sex differences in behavioral patterns of looking impacted categorical learning. Future research, however, should consider potential sex differences in categorization studies and determine if differences are predictive of test performance.

We were particularly interested in how infants' patterns might be changing during familiarization. Changes in the variability of looking patterns could be indicative of learning during this phase. For example, we anticipated that if infants learned the categories quickly, they might have become inattentive or disengaged across the familiarization trials, in which case we would have expected to see a decrease in the variability of their looking patterns across trials. Although infants' variability decreased slightly during the middle portion of familiarization (slight U-shaped curve), their variability did not change much from the beginning to the end of the familiarization phase, nor did infants have significant individual variation in this pattern of behavior. These results indicate that even though infants showed a significant decrease in average looking time from the first familiarization block to the last familiarization block (as per the traditional looking time analysis), they were still attentive and engaged in looking at (or away from) the category exemplars.

Attractor stability. Stimulus characteristics related to attractiveness appeared to influence infant behavior during the pretest phase. In this instance, infants who viewed low attractive faces experienced strong attractor states for the pretest stimuli and weaker look away attractors than infants who saw high attractive faces. Low attractive faces might have initially been attention grabbing (i.e., lower proportions of looking away). Low attractive faces take longer to process than high attractive faces (e.g., Trujillo et al., 2014), which could explain why infants who initially saw low attractive faces attended more to the stimuli than infants who saw high attractive faces. This effect, however, appeared to be short-lived because infants' looking away patterns were quite similar across familiarization and test phases regardless of familiarization condition, and no other significant effects emerged involving the attractiveness of the familiarization conditions. Additionally, we found that infants tended to have a stronger attractor for the to-be-novel stimuli when the variability (i.e., dispersion) of their looking was higher. From the traditional looking time analyses, we also found that infants who would be familiarized to high attractive, high feminine males initially showed a significant preference for the to-be-novel stimuli. These results could suggest that infants potentially detected an initial commonality among the to-be-familiar category stimuli because they saw multiple exemplars of this category across trials. We did not, however, find any linear trends in the strength of infants' pretest attractor states across trials, therefore it is difficult to determine if infants' initial preference for to-be-novel stimuli was a result of cumulative experience across the pretest trials.

We examined the proportion of time infants spent looking toward the stimulus faces across familiarization trials, and found some significant variance in where infants were looking.

In general, infants exhibited an accelerated decrease in looking across trials, but there was significant variance in all aspects of this trend (i.e., significant variance in the initial looking proportion, instantaneous rate of change, and accelerated rate of change across trials). Because these differences in proportion of looking were not associated with familiarization condition, infant sex, or primary caregiver race, it would be difficult to unpack subgroups of infants based on their familiarization profiles without conducting more advanced analyses such as latent class growth analysis or growth mixture modeling (e.g., Jung & Wickrama, 2008). Even though infants' patterns of behavior did not change much during familiarization (i.e., dispersion and visit entropy), on average, infants' attention toward the familiarization stimuli decreased across trials. Taken together these findings suggest that infants' attention toward stimuli decreased due to learning or adaptation to the testing environment and not due to fatigue or disinterest, in which case we likely would have found a significant decrease in infants' overall patterns of looking (i.e., variability) across trials.

An examination of the strength and stability of attractor states during the test phase produced some interesting results. On average, infants showed a significant novelty preference during the last block of trials (as per the traditional looking time analyses). This effect, however, might have been moderated by individual differences in real-world social experiences. Infants with non-Caucasian primary caregivers (PCs) tended to have a linear decrease in the strength of their novelty attractor across test trials, whereas infants with Caucasian primary caregivers had a slight increase in their novelty attractor state across test trials. This decrease in the strength of the novelty attractor for non-Caucasian PC infants could indicate poorer category learning for this subgroup. During familiarization, infants with non-Caucasian PCs did not differ from infants with Caucasian PCs in their variability or patterns of looking toward the familiarization stimuli, but these infants may have had more difficulty retaining categorical information for all test trials. Because non-Caucasian PC infants were viewing faces from an unfamiliar race, their cumulative real-world social experience was less likely to aid in their processing of faces during the testing session. These infants likely had a poorer cognitive representation for the just-learned category that might have been more easily perturbed by the changing stimuli during the test phase. They exhibited their strongest novel category attractor state during the first few test trials, but then perhaps the immediate history of other test trial comparisons “interfered" with the category knowledge they had acquired during familiarization and resulted in a degradation of the just-learned category. Interestingly, these infants did not show a reciprocal increase in the strength of their familiar category attractor, which might suggest that the decrease in their attention to the novel category faces across trials was due to poor retention for the just-learned category and not due to a continued interest in the just-learned category.

The significant preference for novel category faces during the last test block occurred regardless of the test comparison infants saw, which suggests that infants were continuing to learn about the familiarization category during the test phase (albeit this effect was most likely driven by infants with Caucasian PCs). Infants may have used the comparison between test stimuli during the first two test blocks to better encode the just-learned category (Rennels et al., 2016). Simultaneous presentation of differing stimuli allows infants to explore similarities and differences among items and is less burdensome to memory capacity than tasks that employ sequential presentation. For example, paired presentation of within-category exemplars during familiarization has been shown to aid in infant categorization as compared to sequential presentation of within-category exemplars (e.g., Oakes & Ribar, 2005). Twelve-month-old female infants showed a similar novel category preference during the third block of a test phase after being familiarized to one of four categories of male faces that differed in attractiveness and/or masculinity (Rennels et al., 2016).

Interestingly, infants had their strongest familiar category attractor when test comparisons differed in both sex and femininity, but they also exhibited a significant novelty preference during this comparison. Additionally, infants tended to have higher levels of variability (both dispersion and visit entropy) during this test comparison (although this effect was not significant). Taken together, these results suggest that test comparisons in which faces differed in both sex and femininity might have been particularly attention grabbing for infants. Faces in this test comparison were likely the most perceptually dissimilar, and therefore, may have allowed for the most comparative processing. On the other hand, infants had their weakest familiar category attractor and least variability in their overall patterns of looking when test comparisons differed in sex only, but they also exhibited a significant novel category preference for this test comparison. This result suggests that when test comparisons differed only in biological sex, infants experienced a stronger, more stable novel category preference (as compared to test comparisons that differed in both sex and femininity). Not many researchers have measured infants' categorization of faces that differ in multiple dimensions. Rennels et al. (2016) found that infants could categorize male faces by masculinity only but did not show evidence of categorizing when test comparisons differed in both attractiveness and masculinity. Results for our investigation would suggest that infants attend more toward both stimuli when faces differ in two dimensions, therefore detecting a significant preference for the novel category over the familiar category might be difficult.

We also found that during the test phase individual differences in infants' overall patterns of behavior related to the strength of their novel and familiar category attractor states. Infants' proportion of looking toward novel category stimuli and familiar category stimuli increased as their variability increased (i.e., increase in visit entropy and increase in dispersion, respectively). These results are not necessarily surprising because they indicate that the more engaged and attentive infants were during the testing phase, the more they looked toward the test stimuli.

Individual variability. As with Experiment 1, significant random variance among infants existed in almost all growth model analyses. Controlling for aspects of study design and potential individual differences in real-world experience did not always adequately account for variance among infants' behavior, which suggests that other variables may be contributing to infants' performance. Individual differences in infants' physical, social, and emotional development could be related to their behavior during this study. Differences in temperament or working memory capacity could affect infants' attention and retention of stimulus faces, particularly because this testing session was fairly long (> 6.5 min) and involved multiple phases. Not all infants exhibited a decline in looking during familiarization, therefore, a closer examination of infants' familiarization profiles might help explain individual variability in novel- and familiar category attractor states during the test phase.

Individual variability might have also masked group differences in infant behavior related to the condition to which infants had been familiarized. We anticipated that infants who were familiarized to less typical and unfamiliar face types (i.e., low attractive faces and/or males) would have more difficulties forming categories, be more likely to use femininity cues to discriminate among test faces, and show the most dramatic changes between pretest and test phases. We, however, found very few differences associated with familiarization condition. It is difficult to determine if the lack of effects associated with condition were due to infants' equivalent performance across conditions or due to the nature of the analyses conducted. Perhaps the significant individual differences observed in this investigation would have been less apparent if infants' data had been analyzed separately by familiarization condition.

Conclusion. The addition of the dynamic systems analyses helped explain some significant effects in the study. Even though infants did not exhibit many differences in the variability of their looking behavior in general, the variability measures in conjunction with an examination of attractor states allowed us to uncover a more nuanced interpretation of infants' familiarization and categorization abilities. For example, infants had a novelty preference that significantly differed from chance when viewing test comparisons that differed in sex and differed in both sex and femininity, but the nature of these preferences might be somewhat different. For the sex only preference, infants had slightly less variability in their overall looking patterns (i.e., fewer looks, shorter duration of looks and fewer transitions between and away from stimuli). They also had a weak attractor for the familiar category face, therefore the significant group preference for the sex only test comparisons might reflect a stable novelty preference. On the other hand, the significant novelty preference for test comparisons that differed in both sex and femininity was associated with infants' strongest familiar category attractor and higher overall variability in infants' behavior. Therefore, this significant group preference might have been more fluid or flexible and was indicative of a preference that arose from a fair amount of comparative looking. These results suggest that the relation between infants' overall patterns of looking (i.e., variability) and attractor stability might help explain the relative stability (or flexibility) of particular preferences.

Additionally, the role of real-world social experiences impacted infants' categorization abilities. Infants with non-Caucasian PCs exhibited stronger novelty preferences at the beginning of the testing phase that significantly declined across testing trials. This effect was in opposition to the group effect for a significant novelty preference during the last block of test trials. These results indicate that infants with Caucasian PCs may have continued to learn about the familiarized category during testing sessions, whereas infants with non-Caucasian PCs may have formed temporary or unstable category representations during familiarization, which quickly destabilized across differing test comparisons.

Chapter 4: General Discussion

In this investigation we sought to examine the multicausal relation between infants' macrolevel and microlevel social structures. More specifically, we examined the potential constraints infants' real-world experiences with faces imposed upon their on-line preferences for and categorization of male and female faces during lab settings. We assessed the role macrolevel social structures might play in microlevel learning during several different contexts across two research paradigms. We used a dynamic systems perspective that not only informed our analytic approach, but introduced us to the concepts of variability and attractor stability. In both experiments we found evidence of the interconnection between macrolevel social structure and real-time dynamic change. We also discovered that the within person relation between infants' overall patterns of looking (i.e., variability) and attractor stability helped explain the relative stability (or flexibility) of particular preferences and helped us better understand infant behavior in instances when we did not observe significant group preferences.

Influence of Macrolevel Social Structure

Infants appeared to be influenced by their real-world social experiences. Although these influences might have had only a temporary impact on infants' preferences during Experiment 1, they appeared to have a more substantial impact on infants' abilities to form and retain categorical information in Experiment 2. In Experiment 1, the relation between infants' variability and the strength of their female attractor state suggested that infants showed an initial proclivity for familiarity (i.e., females) that was likely influenced by their external experiences with females. Three-month-olds may have been more constrained by their macrolevel social structure than 9-month-olds because they exhibited some group preferences for females, whereas

9-month-olds did not (i.e., in order for group preferences to emerge after aggregation of data, significant preferences had to persist beyond the first few trials of the study).

In Experiment 2, we found that infants' experience with their primary caregiver's (PC) race might have impacted their ability to form and retain categorical information during the testing phase. Infants with non-Caucasian PCs might have formed a weak social category during familiarization, and the immediate history of competition from novel category exemplars across test trials might have led to the destabilization of the novelty attractor state. Conversely, with a more strongly developed category, (i.e., Caucasian PC infants) the immediate history of competition among novel category exemplars might have allowed comparative processing to further solidify the novelty attractor state (Rennels et al., 2016) and resulted in a group novelty preference for the final test block.

Real-world experiences are likely to influence infant behavior during lab settings. Even when researchers randomize trials across participants or control for a priori preferences, the interaction between macrolevel experience and microlevel on-line learning is likely to exist. To help determine how such influences are impacting the outcome for a particular study, researchers should conduct an initial assessment of behavior that is time-dependent. Assessing how behavior changes across the testing session could help determine if real-world experiences have a global impact on behavioral outcomes or if the impact is more local and eventually is overcome by on-line learning during the study. For example, in Experiment 1 we might be inclined to examine infants' preferences separately for the first half and second half of the study, whereas in Experiment 2, we might be better served to examine data separately for infants with Caucasian and non-Caucasian PCs.

Strength and Stability of Attractor States

Our attractor state analyses revealed a rather complex picture of infant behavior during visual preference and categorization studies. We did not always find reciprocity in the strength and stability of the face stimuli attractor states, which suggests that not looking at one stimulus does not necessarily equate to interest in the other stimulus. Infants may prefer to look away rather than look at a competing stimulus, or they may experience a strong attractor state for one stimulus yet still exhibit a significant preference for the other stimulus. For example, during the testing phase of Experiment 2, infants experienced their strongest familiar category attractor when viewing test comparisons that differed in both sex and femininity but also exhibited a significant group preference for the novel category face during this test comparison. These results also suggest that the strength of attractor states is not necessarily equivalent to visual preferences obtained from traditional looking time analyses.

We found within-person changes that were associated with infants' overall patterns of variability and the strength and stability of their attractor states. This link may help us better understand the nature of infants' preferences. If infants exhibit a strong attractor for a particular stimulus, but it is associated with low overall variability (i.e., longer looks, less frequent looks, and stable patterns of looking), then this might indicate that infants are exhibiting a significant preference because they are in a strong, stable state from which it is difficult to escape. A very strong, stable attractor is not necessarily detrimental. Infants engage in second-order face processing, which helps them learn fine grained details about faces (e.g., Bhatt, Bertin, Hayden, & Reed, 2005); therefore, these strong, stable, inescapable attractor states may be a sign that infants are intently processing stimulus characteristics. Strong, stable attractor states, however, may not be a sign that infants are making comparisons and choices based on the characteristics of both stimuli. On the other hand, when infants exhibit strong attractor states that are associated with high variability in looking patterns, this pattern suggests that infants are likely engaged in comparative processing and actively making a choice as to which stimulus they prefer.

Our results suggest that infants are experiencing different types of preference patterns based on age and/or the content of stimuli. The strength of attractor states did not always map onto significant preferences, however, so future research is still needed to determine how variability and attractor stability can inform our understanding of infant behavior. For example, when infants exhibit patterns of strong, stable attractors and little variability, is it a product of being young, less experienced processors who attended intently to whatever might be in front of them, or are infants making an initial decision and then staring at the preferred stimulus? Examining the first few looks of a trial could help address this question. If infants engage in one or two short looks before settling on an attractor state, then they are likely preferring to learn more about one type of stimulus.

Microlevel Changing Patterns of Behavior

We assessed the variability of infants' looking behavior (i.e., overall patterns of change related to duration and frequency of looks) both in terms of moment-to-moment changes related to contextual aspects of the study design (i.e., stimulus characteristics) and in terms of changing dynamics related to adaptation to environmental influences (e.g., Hollenstein, 2013). Because variability does not require an evaluation of the content of behavior, we could determine how infants responded to the testing environment, regardless of their individual preferences. Variability analyses could serve as a valuable tool for ensuring that design manipulations were effective or for determining why participants might not have responded in an anticipated manner. For example, in Experiment 1, we found that 3-month-olds in the blocked condition experienced higher degrees of variability during the first trials of the familiar race block, and in Experiment 2, we found that 12-month-olds had higher variability during the first block of the testing session. Both results fit with our prediction that infants likely noticed these changes in context and experienced a brief period of instability because of them. Higher variability is associated with less stable behavior patterns (e.g., Hollenstein, 2013), therefore, researchers might discover that infants tend not to exhibit stable, group preferences during periods of collective instability.

We also found age related differences in the overall patterns of infant behavior across the testing session. These changes helped us determine if and how infants might have adapted to the testing environment. In Experiment 1, younger and older infants displayed fairly divergent behavioral patterns, which suggested that they might have adapted to the environmental setting in different ways. In general, 3-month-olds' variability increased across trials, whereas 9-month-olds' variability decreased. Younger infants might have first had to gain flexibility in their behavioral patterns (i.e., low dispersion and few transitions between states are markers of inflexibility in behavior; Hollenstein & Lewis, 2006) before they discovered that the testing environment afforded an opportunity for comparative processing. In contrast, older infants might have experienced higher degrees of variability at the beginning of a testing session because of the novelty of being in this fairly unusual testing environment (i.e., perched on their parents' laps in a darkened room and exposed to flashing green balls, whistle sounds, and neutrally expressive pictures of men and women). The lab experience might have acted as a perturbation from their real-world experiences and resulted in a temporary disorganization of their behavior. Older infants, however, appeared to have more stable looking patterns, in general, and we found fewer instances when the variability in their behavior was affected by changes related to the study context such as stimulus characteristics or presentation order. This effect of stable looking patterns was also observed among 12-month-olds during the categorization study. Although the content of their behavior varied (i.e., changing attractor states and group preferences), on average, 12-month-olds' patterns of behavior did not fluctuate greatly across phases of the study or familiarization conditions.

Other studies have also found age related differences in the dynamics of infants' looking behavior. With age, infants tend to engage in shorter looks, more transitions between paired stimuli, and shorter peak looks (i.e., longest looks; e.g., Rose, Feldman, & Jankowski, 2001; Perone & Spencer, 2014). These age related differences have been associated with better discrimination of test stimuli among older infants. Additionally, Perone & Spencer (2014) found that the dynamics of looking during familiarization trials were predictive of discrimination performance, which suggests looking dynamics and discrimination are linked at an individual level. Our investigation extends upon these findings by examining how the current state of looking dynamics and preferences are contingent upon each other. An individual infant may engage in more or less dynamic looking patterns depending on the external context (i.e., stimulus characteristics) and previous history of looking. It may be that not only are short lookers better discriminators, but that when infants have short looks, they tend to show specific preferences, and those same infants may have longer looks during changing situations (or vice versa).

Look Away Behavior

Aslin (2007) emphasized the need to look more closely at infant looking. He advocated for researchers to focus more on the microstructure of infant looking (e.g., looks away, minimum and maximum look durations) rather than solely focusing on the macrostructure of looking as a single dependent measure. Often researchers use look away behavior as a means of determining attention termination. For example, during habituation paradigms, researchers use 1 or 2 s looks away as a criterion for ending a trial (e.g., Aslin, 2007). Our investigation, however, suggests that look away behavior may be a necessary component of information processing. We found instances when higher degrees of overall variability were associated with stronger attractor states, and high degrees of variability inevitably involved both transitions between and away from stimuli. Future research is still needed to determine if the sequencing of looks to looks away is informative. For example, infants may be more likely to make a comparative look from a familiar to novel stimulus, but more likely to transition to an away look after viewing a novel item or after fixating for an extended period of time. Because our SSG analysis involved grids that represented transitions between looks, we could easily accommodate these types of analyses using our current data set. For example, we could determine sequences of looks by mapping individual trajectories on the grid, analyze overall transition patterns by examining the frequency of different types of transitions (i.e., A to B, or A to away), or investigate the probability of a look away occurring based on the previous history of looking. Each analysis could be informative for discovering how looking patterns relate to information processing.

Examining look away patterns in conjunction with overall variability helped us assess infants' attention during testing sessions. In general, we found increases in infants' looking away across trials. These look away patterns, however, were not also associated with dramatic decreases in overall variability of behavior, which suggests that infants engaged in more frequent or longer looks away as the study progressed because of learning and familiarity with the testing environment and not because of fatigue. If looking away had increased due to fatigue or fussiness, we should have found a corresponding decrease in the overall variability of behavior because of sustained looks away. Because we did not find any relation between look away behavior and characteristics related to our stimuli, we cannot determine if infants looked away because of the stimuli. Other researchers, however, have found that infants tend to look away more when viewing very simple and very complex stimuli (e.g., Piantadosi, Kidd, & Aslin, 2014). Infants in this investigation, therefore, may have experienced increasingly stronger look away attractor states across trials because the stimuli became easier to process.

Evaluation of Variability Measures

Dispersion appeared to be a better indicator of infants' variability as compared to visit entropy because dispersion more often related to infants' attractor states. Infants with the most predictable looking patterns (i.e., lowest visit entropy) were those who provided one continuous look toward an attractor state for an entire trial. Although a single look is very predictable, including these data in the analyses of predictable looking patterns may have skewed results in a way that made it difficult to distinguish infants who engaged in other predictable patterns (e.g., looking between stimuli multiple times without looking away) from infants who engaged in more unpredictable, chaotic looking (e.g., a looking sequence with at least one node in all seven potential cells). In only two instances did visit entropy contribute to a better fitting model of infant attractor stability (i.e., for male proportion in the blocked design of Experiment 1 and for novel proportion during the test phase of Experiment 2). In both instances, visit entropy helped account for variance among individuals, but was not necessarily a significant predictor of infants' behavior. Because dispersion included information about look duration and frequency, it might have been a more informative measure of infant looking during relatively short periods of time. Visit entropy, however, may be an effective measure for discerning infant behavior during longer trials in which sequences of looks are more likely to occur or for paradigms in which stimulus presentation is more constant or predictable across trials.

We had expected to find a more consistent link between patterns of variability and the familiarity of the stimuli in our overall variability analyses (i.e., that infants would have more stable looking patterns when viewing familiar race, female, and high attractive faces) but did not find much support for this prediction. This lack of significant effect could be due to infants having rather complex behavioral patterns and preferences (i.e., showing strong and stable attractors in some instances but flexible attractors in other cases). It could also be due to the nature of our data. Since Hollenstein's 2013 guide to SSG analyses, about 23 SSG related studies have been published, many of which have used dispersion (~9) and/or visit entropy (~5) as measures of variability. In most cases, however, the behaviors being measured were not likely to occupy only one cell, the time courses of measurement were usually much longer than 10 to 15 s, and the potential grid sizes were often quite large (i.e., 4 x 4 to 15 x 15 grids). These factors would likely have made differences between individuals, if they exist, easier to detect (i.e., a larger potential state space in which more variability was possible and more time for differences to emerge). In the case of our investigation, infant behavior could be (and occasionally was) restricted to only one cell, our grid size was fairly small (3 x 3), and infants' behavior could occupy only seven potential cells on any given trial. Therefore, the discrepancy between "variable" and "stable" looking patterns may have been quite small and difficult to detect at an aggregate level of analysis.

Implications, Limitations, and Future Directions

Examining differences in groups' behavioral patterns may be an important initial step to consider before conducting analyses. If two groups exhibit different patterns of behavior toward the same set of stimuli or if group patterns differ across experimental conditions, then it may be important to first divide the sample into groups based on the variability of their behavior.

Participants who have very different patterns of behavior toward the same items may also be processing information about these items in different ways, so it may be misleading to assume that their performance will be equivalent or that findings should be interpreted in a similar manner.

Focusing on behavioral patterns might also help researchers create more informed designs. If researchers want to compare processing across groups, perhaps they should first manipulate their study design in a way that allows for both groups to process the information in a similar manner (i.e., equate variability across participants). This could be done by assessing individual differences in variability during warm-up trials (which would likely require on-line coding or eye tracking data and an algorithm for assessing thresholds in variability) or manipulating study design so that younger infants are exposed to stimuli for longer periods of time. Warm-up trials could also serve as an opportunity for participants to adapt to the testing environment, or they could provide a method for dividing infants into subgroups based on baseline variability. Infants with lower variability could be given more exposure to stimuli. For example, Figures 4, 5, 11, and 13 would suggest that not all 3-month-olds exhibited an increase in variability across trials. Some 3-month-olds showed similar trajectories to 9-month-olds; performance on warm-up trials could, therefore, help determine which infants may require additional exposure to stimuli in order to engage in comparative processing.

There is likely a delicate balance between study designs in which comparative processing is possible for most participants and designs in which it is essentially thrust upon participants. Further evaluation of the relation between the variability of behavior and processing of information is needed in order to determine if these design considerations are too egregious. Perhaps the goal should not be to get all participants to produce the same performance output (such as a novelty preference), but rather it might be to measure variability in conjunction with attractor states and stability to help explain the patterns of preferences that do emerge among different participants in similar contexts. For example, lower levels of variability in conjunction with a strong attractor may be a sign that the attractor state is a familiar one because strong stable attractors develop over time and repeated exposure and are marked by more stable patterns of behavior (e.g., Hollenstein, 2013).

Some 3-month-olds have similar patterns of variability as 9-month-olds, but we do not yet know if these similar behavioral patterns equate to similar preference patterns. These 3-month-olds may be advanced and processing information on a level more akin to older infants. Alternatively, very high levels of variability might be associated with attention deficits that lead to an inability to focus attention long enough to process information. Therefore, more research is needed to determine if group norms in variability exist, or if there are optimal levels of variability that might be associated with information processing. Differences in variability are likely to exist based on age, the context of study designs, and complexity of stimuli.

We found a fairly high degree of variability among infants in both experiments. Age related differences in behavior, differences based on real-world social experience, variability in individual growth trajectories, and significant variance across individuals were often prevalent. These individual differences might indicate that processes underlying infant behavior are more idiosyncratic than what can be captured by controlling for aspects of study design and stimulus characteristics. Even though HLM analyses helped uncover some processes underlying infant behavior, few models were well specified (i.e., they did not adequately account for random variance among participants). Alternative analytical approaches might better handle individual variability, such as latent class growth analysis or growth mixture modeling, which can identify subgroups of participants with similar patterns of behavior (e.g., Jung & Wickrama, 2008). These analyses might allow for a better examination of behavior related to context in conjunction with changing patterns across time, thus eliminating the need for overall variability analyses separate from change in variability analyses. Identifying subgroups within the larger infant sample could not only reduce random variance within our sample, but could potentially provide a way to identify different learning processes within a sample. For example, duration of fixations in infancy (i.e., short and long lookers) has been associated with information processing abilities (e.g., Colombo, Kapa, & Curtindale, 2010; Cuevas & Bell, 2014).

Individual infants often responded quite differently to the same testing environment, therefore discovering if groups of infants cluster together based on variability of looking or attractor stability might be informative. Understanding ways in which these subgroups of infants are similar or different may be essential to a richer understanding of infants' behavior. Identifying other potential predictors of infant looking behavior may also contribute to a reduction in individual variance. Various aspects of physical, social, and cognitive development can impact each other in meaningful ways, so identifying relevant variables could lead to a better understanding of infant behavior during research settings. For example, infants who were crawling and spontaneously manipulated toy blocks tended to show novelty preferences during a mental rotation task, whereas infants who were not mobile and did not explore toys tended to show familiarity preferences (Schwarzer, Freitag, and Schum, 2013). Infants who showed more stable patterns in visual recognition memory across trials in a lab setting differed in temperament and environmental factors from infants who had more variable patterns of performance (Wachs, Morrow, & Slabach, 1990). The infants with stable visual working memory tended to have higher scores in temperament measures of adaptability and mood and had home environments that included more regulated nap times and parents who were more verbally responsive to their children and showed or demonstrated more objects to them (Wachs et al., 1990). Every infant who participates in a research study arrives at the lab with a unique set of experiences and preferences that impact their behavior. Each infant is influenced by his current mental and physiological state. These outside influences are undoubtedly important to the child’s performance in the lab. Dynamic systems researchers emphasize the interconnectedness of development. Infants may be constrained by their social or physical contexts, or their levels of motivation or attention may influence behavior (Thelen & Smith, 2006). Being aware of the individual differences among participants and examining how they may relate to behavior in lab settings can help researchers improve upon data interpretations and obtain a better idea as to why infants may behave in the manner in which they do.

Individual variability is fairly paramount in infant development. Therefore, the best strategy for understanding infant behavior may not necessarily be to find variables that explain it away until all that remains is that one kernel of group similarity. Perhaps the goal should be to discover ways in which subgroups are similar and determine if they respond in unique ways that may even be counter to aggregate group effects. Uncovering the relation between changing dynamics and attractor strength and stability helped explain some within- and between-person differences in our investigation, but additional analyses and approaches may be needed to arrive at a more coherent picture of infant performance in preferential looking and categorization tasks.

Appendix A: Summary of Significant Results from Experiment 1

Table 21

Summary of Significant Results from Experiment 1

Analysis	Randomized condition	Blocked condition
	Significant effect Interpretation	*Significant effect* Interpretation
Traditional infant looking-time		
PTLT to chance (50%)	*3mo/low att. > .50* - 3mo PTLT to low attractive females was sig greater than chance *Fam. race/low att. > .50* - Infant's PTLT to familiar race/low attractive females was sig greater than chance	*3mo/unfam. race/low att. > .50* - 3mo PTLT to unfamiliar race, low attractive females was sig. greater than chance
Dynamic systems perspective		
Overall variability (SAS proc mixed)		
Dispersion (DISP)	*Main effect of infant age* - 9mo had higher variability (DISP) than 3mo	*Infant Age x Race Familiarity x Race Order* - 9mo had higher variability (DISP) than 3mo ○ exception: 3mo viewing fam. race during Tr1 & 2 did not differ from 9mo viewing any fam. race - For fam. race, 3mo variability sig. decreased from Tr1 to Tr3 - 3mo variability during fam. Tr1 sig. greater than 3mo during unfam. Tr1 *Infant Sex x Race Familiarity x Race Order* - For fam. race, female variability sig. decreased from Tr2 to Tr3 - For fam. race, female variability on Tr3 was sig. lower than male variability on Tr1

Visit entropy (ENT)	*Main effect of infant age* - 9mo had higher variability (ENT) than 3mo	*Infant Age x Race Familiarity* - 9mo had higher variability (ENT) than 3mo - 3mo had higher variability during fam. race blocks than during unfam. race blocks *Infant Age x Race Order* - 9mo had higher variability (ENT) than 3mo - 3mo variability sig. decreased from Tr2 to Tr3
Changes in variability (Growth curve)		
Dispersion (DISP)	*Linear model with infant age* - Initially 9mo had higher variability (DISP) than 3mo - 3mo sig. increased variability across trials - 9mo decreased variability slightly across trials	*Linear model with infant age* - Initially 9mo had higher variability (DISP) than 3mo - 3mo sig. increased variability across trials - 9mo decreased variability slightly across trials
Visit entropy (ENT)	*Linear model with infant age* - Initially 9mo had higher variability (ENT) than 3mo - 3mo sig. increased variability across trials - 9mo decreased variability slightly across trials	*Linear model with infant age* - Initially 9mo had higher variability (ENT) than 3mo - 3mo sig. increased variability across trials - 9mo decreased variability slightly across trials
Attractor stability (Growth curve)		
Female proportion	*Model with att., DISP, and infant age* - 3mo had higher female prop. than 9mo - For 3mo higher variability (DISP) related to lower female prop. - For 9mo higher variability (DISP) related to higher female prop. - 3mo female prop. decreased from low to medium to high att. - 9mo had stable looking to females across att.	*Model with DISP and infant age* - 3mo had higher female prop. than 9mo - For 3mo higher variability (DISP) related to lower female prop. - For 9mo higher variability (DISP) related to higher female prop.
Male proportion	*Model with att. and infant age* - 3mo and 9mo had similar male prop. for low att. - 3mo’s male prop. increased from low to medium to high att. - 9mo had stable looking to males across att.	*Model with ENT and infant age* - 3mo had higher male prop. than 9mo - For all infants, increase in variability (ENT) related to decrease in male prop. (but n.s.)

Away proportion	*Linear model with DISP and infant age* - Initially 9mo looked away more than 3mo - Both ages showed gradual increase in away looking across trials - As infants' variability (DISP) increased, their prop. of looking away increased	*Linear model with DISP and infant age* - Initially 9mo looked away more than 3mo - Both ages showed gradual increase in away looking across trials - As 3mo variability (DISP) increased, their prop. of looking away increased - As 9mo variability increased, their prop. of looking away decreased

att. = attractiveness, fam. = familiar, unfam. = unfamiliar, prop. = proportion, mo = months

Appendix B: List of Stimulus Faces for Sets A and B for All Conditions in Experiment 2

Table 22

List of Stimulus Faces for Sets A and B for All Conditions in Experiment 2

Familiarization condition	Familiarization phase	Test phase		
		Differ in sex	Differ in femininity	Differ in both sex and femininity
High attractive, high feminine female (HHF)				
Set A	HHF1, HHF2, HHF3, HHF4	HHF5 – HHM5	HHF7 – HLF1	HHF6 – HLM1
Set B	HHF4, HHF5, HHF7, **HHF8**	HHF6 – HHM5	HHF2 – HLF1	HHF3 – HLM1
High attractive, high feminine male (HHM)				
Set A	HHM1, HHM2, HHM3, HHM4	HHM5 – HHF5	HHM6 – HLM2	HHM7 – HLF2
Set B	HHM2, HHM3, **HHM8**, **HHM9**	HHM5 – HHF6	HHM6 – HLM1	HHM1 – HLF2
Low attractive, low feminine female (LLF)				
Set A	LLF1, LLF2, LLF3, LLF4	LLF5 – LLM1	LLF6 – LHF1	LLF7 – LHM1
Set B	LLF2, LLF3, LLF7, **LLF8**	LLF1 – LLM7	**LLF9** – **LHF3**	**LLF10** – **LHM3**
Low attractive, low feminine male (LLM)				
Set A	LLM2, LLM3, LLM4, LLM5	LLM1 – LLF2	LLM6 – LHM2	LLM7 – LHF2
Set B	LLM1, LLM2, LLM6, **LLM9**	LLM3 – LLF3	**LLM10** – **LHM3**	LLM7 – **LHF3**

Stimuli that appeared only in set B are in **BOLD**

Appendix C: Summary of Significant Results from Experiment 2

Table 23

Summary of Significant Results from Experiment 2

Analysis	Pretest Phase	Familiarization Phase	Test Phase
	Significant effect Interpretation	*Significant effect* Interpretation	*Significant effect* Interpretation
Traditional infant looking-time			
PTLT to chance (50%)	*"novel" HHM > .50* - Infants in HHM condition preferred "novel" stimuli (HHF, HLM, HLF) over HHM faces		*Diff. in sex / Diff. in sex & fem. > .50* - treated diff. in sex as novel category - no distinction for diff. in fem. only *3rd block > .50* - regardless of comparison, infants showed novelty pref. during 3rd block
LT during familiarization		*Main effect for familiarization block* - Infants' LT sig. decreased from first block to last block	
Dynamic systems perspective			
Overall variability (SAS proc mixed)			
Dispersion (DISP)	*Main effect of infant sex* - Males had higher variability (DISP) than females	*Main effect of infant sex* - Males had higher variability (DISP) than females	*Familiarization Condition Sex x Test Comparison x Test Comparison Order* - no significant effects *Main effect of test comparison order* - Higher variability (DISP) during 1st test block than during 2nd block
Visit entropy (ENT)	*No significant effects*	*No significant effects*	*Familiarization Condition Sex x Test Comparison x Test Comparison Order* - no significant effects

			Main effect of test comparison order - Higher variability (ENT) during 1st test block than during 2nd block
Changes in variability (Growth curve)			
Dispersion (DISP)	*Model with infant sex* - Males had higher variability (DISP) than females	*Linear and quadratic model* - U-shaped trajectory indicated decreased variability (DISP) during middle trials but then variability increased again in later trials	*Linear model with test comparison* - Infants had slight decrease in variability (DISP) across trials (n.s.) - Lowest variability when test faces differed in sex and most variability when differed in both sex and fem. (n.s.) ○ sex < fem. < both
Visit entropy (ENT)	*No significant effects*	*Model with infant sex* - Males had higher variability (ENT) than females	*Linear model with test comparison* - Infants had slight decrease in variability (ENT) across trials (n.s.) - Lowest variability when test faces differed in sex and most variability when differed in both sex and fem. (n.s.) ○ sex < fem. < both
Attractor stability (Growth curve)			
Novel proportion	*Model with DISP* - As infants' variability (DISP) increased, their prop. of looking at stimuli increased		*Linear model with ENT and PC race* - As infants' variability (ENT) increased, their prop. to novel increased - Infants w/ non-Caucasian PCs decreased looking to novel across trials - Infants w/ Caucasian PCs slightly increased looking to novel across trials

Familiar proportion	*Model with familiarization condition attractiveness* - Infants who saw low att. faces had higher prop. of looking to stimuli than infants who saw high att. faces		*Model with test comparison and DISP* - As infants' variability (DISP) increased, their prop. to familiar increased - Infants had increased prop. to familiar across test comparisons ○ sex < fem. < both
Away proportion	*Model with familiarization condition attractiveness* - Infants who saw low att. faces had lower prop. of looking away than infants who saw high att. faces		*Linear and quadratic model* - Inverted U-shape indicating increase in looking away during middle trials but then looking away decreased again in later trials
Looking proportion		*Linear and quadratic model* - U-shaped trajectory indicated decreased looking during middle trials but then looking increased again in later trials	

HHM = high attractive, high feminine males; HHF = high attractive, high feminine females; HLM = high attractive, low feminine males; HLF = high attractive, low feminine females; diff. = differed or differences; fem. = femininity; att. = attractiveness; prop. = proportion; PC = primary caregiver; fam. = familiar or familiarization; comp. = comparison

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Younger, B. A., & Fearing, D. D. (1999). Parsing items into separate categories: Developmental change in infant categorization. *Child Development*, *70*(2), 291-303. doi:10.1111/1467-8624.00022

Curriculum Vitae

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EDUCATION

Ph.D.
University of Nevada, Las Vegas
Area: Experimental Psychology
Dissertation: Examining the dynamics of infant face processing using state space grids
Advisor: Jennifer L. Rennels. Ph.D.
Expected December 2015

M.A.
University of Nevada, Las Vegas
Area: Experimental Psychology
Thesis: Do toddlers exhibit same-sex preferences for adult facial stimuli?
Advisor: Jennifer L. Rennels, Ph.D.
August 2012

B.A.
University of Nebraska-Lincoln
Major: Psychology
Minors: Mathematics, English, Political Science
Honors Thesis: Auditory representation of visual data for blind and visually impaired students
Advisor: John H. Flowers, Ph.D.
May 2005 – Highest Distinction

PROFESSIONAL EXPERIENCE

Graduate Research Assistant
Department of Psychology at University of Nevada, Las Vegas
Fall 2006 – present
Supervisor: Jennifer L. Rennels, Ph.D.

Design experiments using E-Prime, Qualtrics, Adobe Photoshop, Adobe Pro, QuickTime, and Habit X software
Data compilation and analysis using MATLAB, SPSS, Excel, and Access
Prepare and edit manuscripts for publication
Interview, hire, train, and supervise research assistants
Edit and grade student research papers

Strategic Plan Graduate Research Assistantship
Department of Management, Entrepreneurship, and Technology, Lee Business

School at University of Nevada, Las Vegas
Fall 2010-Spring 2013
Supervisor: Ken Peffers, Ph.D.

Literature review, study design, and data collection for a three-phase qualitative study involving interviews, observation, and scenario-based surveys

Participant recruitment and organization of data collection sights

Data analysis involving thematic clustering and application of nonlinear regression to cumulative concepts

Instructor

Department of Psychology at University of Nevada, Las Vegas
Fall 2008
Introduction to Psychology

MANUSCRIPTS

Rennels, J. L., Kayl, A. J., Langlois, J. H., Davis R. E., & Orlewicz, M. (2016). Asymmetries in infants' attention toward and categorization of male faces: The potential role of experience. *Journal of Experimental Child Psychology, 142*, 137-157. doi:10.1016/j.jecp.2015.09.026

Rennels, J. L., & Kayl, A. J. (2015). Differences in expressivity based on attractiveness: Target or perceiver effects? *Journal of Experimental Social Psychology*, *60,* 163-172. doi:10.1016/j.jesp.2015.05.012

MANUSCRIPTS IN PROGRESS

Rennels, J. L., & Kayl, A. J. The trajectory of the positive expressivity-attractiveness association: Developmental and sex differences. Draft available.

Rennels, J.L., & Cummings, A.J., & Kayl, A.J. Contextual factors affect infants' interest in female and male faces: Evidence of graded facial representations. Draft available.

CONFERENCE PRESENTATIONS / TALKS

Peer-Reviewed

Kayl, A. J. & Rennels, J. L. (2014, September). The dynamics of infants' interest in females and males: A recurrence quantification analysis. Poster presented at the Society for Research in Child Development Special Topic Meeting: Developmental Methodology, San Diego, CA.

Rennels, J. R., Cummings, A. C., & Kayl, A. J. (2014, September). Understanding what's in a look. Poster presented at the Society for Research in Child Development Special Topic Meeting: Developmental Methodology, San Diego, CA.

Rennels, J. L., Kayl, A. J., & Zebrowitz, L. A. (2013, June). Facial attractiveness during childhood predicts females' positive expressivity during adulthood. Presented at the annual meeting of the Jean Piaget Society, Chicago, IL.

Noles, E. C., Rennels, J. L., & Kayl, A. J. (2012, June). Dynamic presentation does not augment infants' intermodal knowledge of males. Poster presented at the XVIII Biennial International Conference on Infant Studies, Minneapolis, MN.

Rennels, J. L., Kayl, A. J., & Davis, R. (2012, June). Age differences in infant categorization of male faces: Cumulative experience with female faces shapes male categories. Talk presented at the XVIII Biennial International Conference on Infant Studies, Minneapolis, MN.

Kayl, A. J. & Rennels, J. L. (2012, April), Toddlers' visual preferences for adults: The impact of gender knowledge and real-world experience. Poster presented at the Fifth Gender Development Research Conference, San Francisco, CA.

Kayl, A. J. & Rennels, J. L. (2011, July). Toddlers' preferences for same-sex adult facial stimuli. Poster presented at the 17th biennial Australasian Human Development Association conference, Dunedin, New Zealand.

Rennels, J. L., Juvrud, J., & Kayl, A. J. (2011, July). How facial appearance, health, and sex-typed attributes are related. Poster presented at the 17th biennial Australasian Human Development Association conference, Dunedin, New Zealand.

Rennels, J. L. & Kayl, A. J. (2010, May). Beauty is positive: The relationship between attractiveness and perceived emotional expression. Poster presented at the 22nd annual convention for the Association for Psychological Science, Boston, MA.

Glover, V., Rennels, J. L., Kayl, A., & Cummings, A. J. (2010, March). Improving infant recognition of male faces. Poster presented at the XVII Biennial International Conference on Infant Studies, Baltimore, MD.

Rennels, J. L., Kayl, A., Cummings, A. J., & Glover, V. (2010, March). Infants categorize prototypical faces by sex but rely on femininity cues to categorize less prototypical faces. Poster presented at the XVII Biennial International Conference on Infant Studies, Baltimore, MD.

Rennels, J. L., Glover, V., Cummings, A. J., & Kayl, A. (2010, March). How infants represent faces. Poster presented at the XVII Biennial International Conference on Infant Studies, Baltimore, MD.

Ramsey-Rennels, J. L., & Kayl, A. J. (May, 2007). Faces are rated similarly regardless of static or dynamic presentation. Poster presented at the Association for Psychological Science 19th annual Convention, Washington, D.C.

Other

Kayl, A. J. & Verba, S. (March, 2015). Baby and child rebel lab: Methodological considerations when studying infants. For research methods in social sciences course, College of Southern Nevada, Las Vegas, NV.

Peffers, K. & Kayl, A. J. (2013, November). Functional requirements engineering for blind users. Presentation for research seminar at Department of Management, Entrepreneurship, and Technology, Lee Business School, University of Nevada, Las Vegas, NV.

Rennels, J. L., Cummings, A. J., Glover, V. A., & Kayl, A. J. (November, 2008). Infant categorization of males and females. For experimental proseminar, Department of Psychology, University of Nevada, Las Vegas, NV.

Glover, V. A. & Kayl, A. J. (February, 2007; September, 2007; March, 2008; March 2010; February, 2011; November, 2012; February, 2014). Baby and child rebel lab: Methodological considerations when studying infants. For research methods in social sciences course, College of Southern Nevada, Las Vegas, NV.

AWARDS / GRANT

September 2014	Graduate & Professional Student Association Travel Grant at University of Nevada, Las Vegas
June 2014	Liberal Arts Ph.D. Student Summer Faculty Research Award recipient, University of Nevada, Las Vegas

April 2012	Graduate & Professional Student Association Travel Grant at University of Nevada, Las Vegas
June 2012	Graduate & Professional Student Association Travel Grant at University of Nevada, Las Vegas
July 2011	Graduate & Professional Student Association Travel Grant at University of Nevada, Las Vegas
May 2010	Graduate & Professional Student Association Travel Grant at University of Nevada, Las Vegas
March 2010	Graduate & Professional Student Association Travel Grant at University of Nevada, Las Vegas
June 2009	Graduate & Professional Student Association Travel Grant at University of Nevada, Las Vegas
May 2007	Graduate & Professional Student Association Travel Grant at University of Nevada, Las Vegas
2000 – 2005	Dean’s List at University of Nebraska – Lincoln
2000 – 2004	Regents Scholarship at University of Nebraska – Lincoln
2000 – 2004	Peter Kiewit Foundation Distinguished Scholar Program at University of Nebraska – Lincoln
Spring 2004	Wolfe Award Outstanding Undergraduate Psychology Major Honorable Mention at University of Nebraska – Lincoln

SERVICE

2006 – present	Undergraduate Mentor
2008 – 2012	Developmental Emphasis Committee – Student Representative
2009 – 2010	Psychology Representative to the Graduate & Professional Student Association
2008 – 2009	Secretary for the Experimental Student Committee
2007 – 2008	Vice President for the Experimental Student Committee

PROFESSIONAL AFFILIATIONS

2010 – present	International Society of Infant Studies
2007 – present	Association for Psychological Science
2005 – present	Phi Beta Kappa
2003 – present	Psi Chi